IAEA-TECDOC-1445

Development of protocols for corrosion and deposits evaluation in pipes by radiography

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FOREWORD

The International Atomic Energy Agency is promoting industrial applications of non-destructive testing (NDT) technology, which includes radiography testing (RT) and related methods, to assure safety and reliability of operation of nuclear, petrochemical and other industrial facilities.

In many industries such as petroleum, power stations, refineries, petrochemical and chemical plants, desalination pipelines and urban gas installations, the reliability and safety of equipment can be substantially influenced by degradation processes such as corrosion, erosion, deposits and blocking of pipes which can seriously affect the security and consistency. One of the most important parameters in a piping or pipeline to be monitored and measured is the wall thickness. Among NDT methods, radiography has the advantage in that in the process of an inspection it eliminates the need for the costly removal of the pipe insulation and also the added benefit that it can be carried out in high temperature environments.

The Coordinated Research Project (CRP) on Validation of Protocols for Corrosion and Deposits Determination in Small Diameter Pipes by Radiography (CORDEP) was implemented from 1997 to 2000 with the participation of 11 NDT laboratories from Algeria, China, Costa Rica, France, India, Republic of Korea, Malaysia, Sri Lanka, Syrian Arab Republic, Tunisia and Turkey. The CRP tested and validated radiographic measurement of corrosion and deposits in straight and bent pipes made of carbon or stainless steels corroded/eroded on the outer or inner surfaces with or without insulation.

Each participating laboratory produced three test specimens of straight and bent pipes containing natural as well as simulated corrosion defects. Typical diameters of these pipes were up to 168 mm. Radiography using X ray machines and radioisotopes of Iridium-192 and Cobalt-60 in conjunction with radiographic film using single and double wall penetrations for total inspection was performed. Selected areas showing corrosion were then inspected using the tangential radiography technique combined with the relevant system of corrosion/erosion evaluation through measurement of the radiographic film density. Selected specimens along with essential documents were sent to the laboratories in agreement holder countries for verification of the experimental results using analogue as well as digital image processing for interpretation of radiographs.

Research coordination meetings were held to review the progress and the workplan during 1997 and 2000. The final and concluding meeting of this CRP was held in Vienna from 4 to 8 September 2000. This TECDOC contains not only the results of the participating laboratories after their review and compilation, but also the individual country reports.

This TECDOC provides procedures and protocols for radiography applications in monitoring corrosion and deposits in pipes. It will assist NDT laboratories in Member States in assessing plant life through the use of NDT technologies. The report is intended for NDT specialists and managers of industry.

The IAEA acknowledges the valuable contribution of all the participants in the CRP. The IAEA officer responsible for this TECDOC was A.A. Khan of the Division of Physical and Chemical Sciences.

EDITORIAL NOTE

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SUMMARY

1. SCIENTIFIC BACKGROUND

The Coordinated Research Project (CRP) on Validation of Protocols for Corrosion and Deposits Determination in Small Diameter Pipes by Radiography (CORDEP) was organized from 1997 to 2000. There was participation by eleven NDT research laboratories from Algeria, China, Costa Rica, France, India, Rep. of Korea, Malaysia, Sri Lanka, Syria, Tunisia and Turkey. The overall objective of the CRP was to test and validate radiographic measurements for monitoring corrosion and deposits in straight and bent pipes made of carbon or stainless steels corroded/eroded on the outer or inner surfaces with or without insulation.

The CRP tested radiographic techniques (using Ir-192, Co-60 and X ray sources) for evaluation of artificial defects, deposits and simulated or natural corrosion attack on carbon steel and stainless steel pipes with diameters up to 168 mm (so-called small diameter pipes) with and without insulation.

The specific objectives of the CRP were:

- full inspection identifying the corrosion attack across the wall and on the perimeter of the pipe by radiography;
- local inspection of selected areas for determination of wall thickness;
- verification of radiographic results by ultrasonic and destructive testing measurements whenever appropriate and through round robin testing (validation).

1.1. NDT FOR SAFETY AND RELIABILITY OF INDUSTRIAL PLANTS

The reliability and the safety of industrial equipment in the petroleum industry and power plants are substantially influenced by degradation processes such as corrosion, erosion, deposits and blocking of pipes, which might reduce production, cause leaks, fires or unpredictable and costly shutdowns due to repair and replacement. The condition of critical components in these industries can be monitored by the proper use of NDT inspection methods even while the plant is in operation, thus making possible the planning of component replacements, repairs, deposit removal and shutdowns. Preventive and corrective maintenance protects the environment and the public against excessive risk of industrial disasters.

Piping is the most important means of transporting liquid and gaseous substances. As a result of economic development, a large amount of piping construction has been carried out in the world. A considerable proportion of piping is used in power stations, petroleum and chemical plants in transporting water, steam, petroleum and chemical products at moderate or high temperatures. This piping is usually covered by thick insulation materials, such as asbestos, nylon cloth, concrete or lime. Because the transported media usually have high pressure, poisonous and combustible characteristics, any leakage or explosion will cause pollution, casualties and immense economic loss.

One of the most important parameters in a pipeline to be monitored and measured is the wall thickness. Only the radiographic method assures inspection without costly removal of insulation material during operation of the plant. An additional advantage is that radiographic techniques can even be applied in high temperature environments. Radiographic evaluation of the deposits/scales in pipes (insulated or not) is also an effective NDT technique. The data is examined by radiography interpreters whose task consists of measuring and quantifying wall thickness.

1.2. CORROSION AS A MAJOR INDUSTRIAL PROBLEM

With the exception of some noble metals, all metals (and alloys) are subject to deterioration caused by corrosion. Corrosion is generally defined as a degradation of a material or its properties because of its reaction with environment. Corrosion reaction is electrochemical in nature, i.e. it involves transfer of electrons. It requires an anode, cathode and electrolyte.

It is always the anode that undergoes corrosion or oxidation reaction. Buildings, ships, machines, power plant equipment, oil and gas pipelines, bridges and automobiles are all subjected to attack by the environment. But while corrosion itself cannot be totally prevented, it can be controlled in order that problems do not reach the severity as shown below (Fig. 1).

FIG. 1. Corrosion in pipes.

Corrosion often renders pipes useless and ultimately they may have to be scrapped. Several estimations have arrived at the conclusion that the total annual corrosion costs in the industrialized countries amount to about 4.6% of gross national product.

The unit of measurement for the corrosion rate of a coupon or pipe is 'mils per year' (abbreviated as mpy). A mil is one thousandth of an inch that means 0.0254 mm or 25.4 µm. The corrosion taking place within piping systems depends on many factors. Whereas condenser water corrosion rates of 1–2 mpy were typical only a decade ago, it is now common to find system-wide corrosion rates of 5 mpy and greater — occasionally as high as 20 mpy.

While certain unavoidable factors have contributed to generally higher corrosion rates, it remains clear that the service life of most piping systems could be greatly extended by giving more serious attention to corrosion control. Even though monitoring corrosion rates through the use of steel corrosion coupons is somewhat helpful, their accuracy is often questioned. Most building operators and engineers would consider the difference between a 3 mpy and 6 mpy corrosion rate as insignificant, although the net effect over many years may be premature failure.

The major corrosion forms investigated include the following:

Uniform or general corrosion refers to corrosion attack proceeding uniformly over the entire exposed surface. It results in uniform thinning leading to eventual mechanical failure.

Galvanic corrosion occurs when two dissimilar metals in electrical contact are placed in electrolyte. The less corrosion resistant material becomes anodic and more corrosion resistant material becomes cathodic, causing accelerated corrosion of the former.

Pitting corrosion is a form of extremely localized corrosion where the depth of attack is usually greater than or equal to the diameter of attack. It results in a hole in the component without much wall thinning in the adjacent area.

Deposit corrosion: Deposit attack or under-deposit attack is defined as the corrosion occurring under or around a discontinuous deposit on a metallic surface". It is sometimes also referred to as 'crevice corrosion'.

Intergranular corrosion (IGC) refers to localized attack at or near grain-boundaries. It is attributed to impurity solute segregation, precipitation or alloying element depletion making the grain-boundary region anodic. Austenitic stainless steel undergoes IGC due to chromium carbide precipitation and chromium depletion near grain boundaries (sensitization).

Selective leaching refers to selective removal of one alloying element from a solid solution alloy by corrosion process. Brass, which is a Cu-Zn alloy, undergoes dezincification.

Erosion corrosion refers to an increase in the rate of attack of a metal surface due to relative movement between a corrosive fluid and the metal surface. There is a critical fluid flow velocity for each metal and alloy. This type of corrosion is observed on pipe-bends and elbows, impellers and heat exchanger tubes.

Stress corrosion cracking (SCC) refers to cracking caused by the conjoint action of tensile stress and a specific corrosive environment. There is a specific metal environment combination (e.g. stainless steel – chloride solution) which leads to SCC. There is a threshold stress or stress intensity factor for SCC to occur.

Corrosion fatigue (CF) usually follows a transgranular path and does not exhibit branching.

From the point of view of application of NDT techniques, the modes of corrosion described above can be classified into four groups. They are:

- Large area loss of metal thickness such as uniform corrosion or galvanic corrosion
- Local area of loss of metal thickness such as pitting and deposit corrosion
- Loss of metal along a microscopic path without significant wall reduction such as IGC
- Cracking as in hydrogen damage such as SCC and CF.

Different NDT techniques are applicable to detect the detriment due to each of above.

1.3. PIPE INTERIOR RUST DEPOSITS

A deposit is an accumulation of transported or corroded materials on the wall or pipe bottom. The interior of any section of piping can show a wide range of deposit characteristics - those characteristics and their severity being generally dependent on piping service, followed by physical orientation and location. Accumulated deposits may also create conditions favorable to extremely destructive microbiologically influenced corrosion, so-called deposit corrosion. Deposit corrosion is associated with stagnant areas (e.g., crevices), with the intrusion of foreign matter into environment, lack of drainage and difficulty of surface cleaning.

Iron oxide and rust products are the main deposits. In its oxidized form, steel produces approximately 20 to 25 times it original volume in iron oxide or rust product. This by-product is often found in horizontal lines and at low flow areas, accumulating in sufficient volume to produce under-deposit corrosion, heat transfer loss, and flow rate problems.

Examples of old condenser systems, having accumulation of rust deposits in horizontal distribution lines are shown in figure 2.

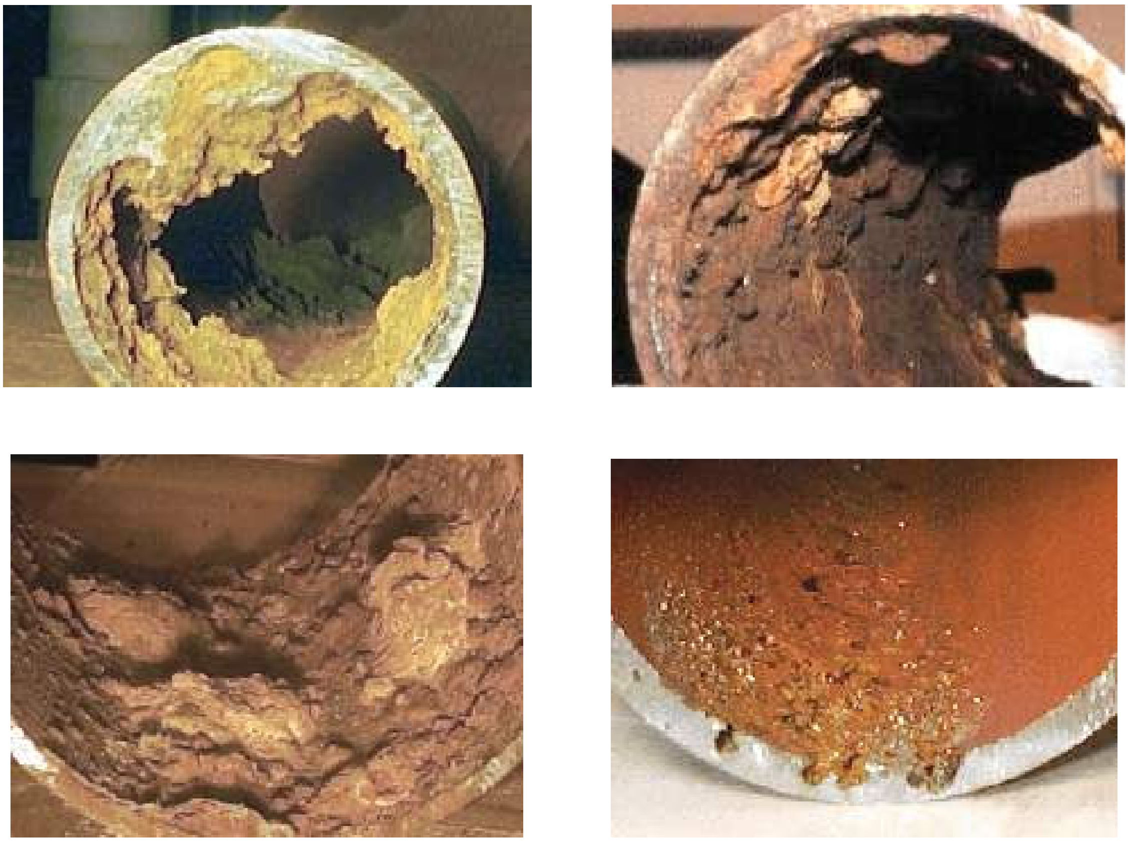

FIG. 2. Typical pipe rust deposits.

1.4. DETECTION OF CORROSION AND DEPOSITS BY NDT

A major inspection challenge facing the factory process industries is how to examine insulated piping for blockage and corrosion, especially for corrosion under the insulation and internal erosion. This problem is especially troublesome for the petrochemical, refining, utility, mining and paper industries.

Piping degradation caused by corrosion and erosion are by far the most prevalent failure mechanisms in various process piping systems. Pipe degradation is usually caused by external corrosion under the insulation, internal corrosion caused by a variety of mechanisms, or internal erosion from the flowing product.

The common methods for locating corrosion and deposit problems in piping involve tangential X and gamma ray radiography and ultrasonic thickness testing. Both methods produce accurate results for pipe thickness measurements.

The non-destructive approach to corrosion and deposit evaluation has additional advantages. For example, once a system is in place and functioning well, it is often unwise to disrupt it by cutting or disassembling; experience has shown that difficulties have arisen as a result of destructive examinations. Non-destructive examination can often be performed at convenient times and need not necessarily result in the shutdown of operations. From the economic point of view non-destructive testing procedures appear to have particular promise in corrosion evaluation.

1.4.1. NDT methods other than radiography

Ultrasonic inspection is a common method for measurement of wall thickness on pipes and vessels. In its normal application, only a small portion of the surface is inspected, which may miss major defects. Also the technique is normally not sensitive to defects such as pitting.

Ultrasonic testing has two limitations. First, it needs insulation to be removed for the measurement. Removal of insulation and refixing it requires a much longer time than the actual testing time. It thus adds to plant down-time.

Second, even for a non-insulated pipe, the influence of the surface condition is very strong. If the corroded surface is the probe contact surface, wall thickness measurement can vary by as much as 40–50 per cent. Even for far-side corrosion, the accuracy of digital thickness gauges is not satisfactory if the opposite surface has become uneven. Local pits with a conical profile also interfere with the measurements.

In short, the main drawbacks of the ultrasound method are:

- It requires removing and replacing a plug of insulation,
- The surface must be cleaned,
- It is slow and expensive.

The other method of promise has been magnetic flux leakage (MFL). This has been particularly successful in the instrumented inspection of oil pipelines in the petroleum industry. Many designs use pipe inspection gauges that travel with the liquid in the pipe, and any insulation outside is inconsequential. In principle, the MFL can also be used externally without removing the insulation, but has not been popular in practice.

Infrared thermography can also be used to find hot spots at corroded locations. But if insulation is installed and effective, then thermography is ruled out. Some attempts have been made to apply eddy current techniques and radioisotope gamma radiometry for assessing the remaining wall thickness in corroded pipes, with limited success.

In summary, most NDT methods other than radiography suffer a handicap if the insulation is to be left intact. They also cannot give a profile of corrosion in terms of area or depth. Radiography with a wide range of available radiation energy, from low kV X rays to Co-60 gamma rays, can be safely applied even with insulation installed.

1.4.2. Radiography in wall thickness assessment

It is believed that radiography has distinct advantages in the assessment of degradation problems because:

- Insulation and paint need not necessarily be removed for evaluation by radiography.
- The radiographic method enables the measurement of one of the most important parameters in piping, namely the remaining wall thickness during operation of the plant.
- The attacked area shown on the radiograph can give some indication of the nature of the attack as well as the degree of the attack.
- Evaluation can be made on complex parts, the insides of which are not accessible and, therefore, cannot be visually examined without destroying the part.
- Deposits and other materials associated with the corrosion problems are often shown by the radiograph.
- The radiographic test does not require a smooth external surface.
- The radiograph is a permanent record. Evaluations of the radiograph therefore can be made in the laboratory. Also periodic examinations can establish the rates of corrosive attack.

Radiography is effective in making a diagnosis in the following conditions:

- Internal deposits: radiography has been proven to be very useful in detecting different kinds of internal deposit.
- Pitting corrosion: radiography can detect pits very easily. The depth of a pit can be determined by measuring the densities of the pitted and sound areas.
- Thickness loss: this can be determined by measuring the radiographic densities or by tangential radiography.
- Corrosion fatigue cracking: radiography is a very useful tool for detecting and evaluating corrosion fatigue cracks.
- The serious stages of stress corrosion cracking can be revealed by radiography only.

However, radiography has the limitation that access to both sides of the part is required; the radiation source is to be placed on one side and the film on the other. In fact, the main drawbacks of the radiography method are:

- It shows only a small area of pipe.
- It requires that the area be roped off for radiation safety.
- It is slow and expensive.
- Stress corrosion cracking: when this type of crack progresses, it becomes detectable by the ultrasonic method.

In view of the importance of radiography in corrosion and deposit depth measurement, the IAEA launched a CRP to formulate a standardized procedure in this regard. As many countries were interested in the subject, a format of round robin testing was chosen to carry out the investigations. It was also decided to propose a draft ISO standard on this subject at the end of the project.

2. THEORETICAL ASPECTS RELATED TO RADIOGRAPHY

2.1. INTRODUCTION TO RADIOGRAPHY

Radiography is one of the oldest NDT techniques, which permits an "inside view" of the material under test. X or gamma rays are projected onto a specimen under examination and the intensity of radiation transmitted through the object is recorded using a photosensitive film, widely known as industrial X ray film. After the exposure, the film is chemically processed and the radiograph is thus obtained. The radiograph is viewed against an illuminator and interpreted. The resulting shadowgraph shows the dimensional features of the part. Possible imperfections are indicated as density changes on the film in the same manner as a medical X ray shows broken bones. The general arrangement for radiography of an object is shown in Figure 3.

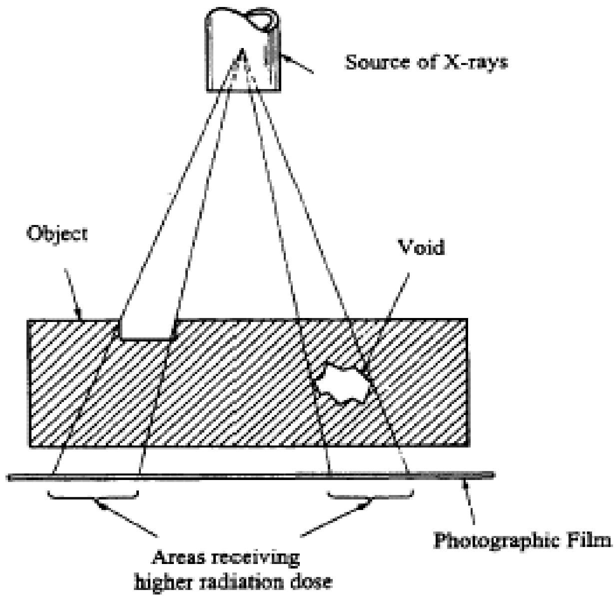

FIG. 3. A typical radiography set-up.

2.1.1. Radiation sources

X ray sources: X rays are generated by means of specially designed high vacuum tubes (X ray tubes). When electrically operated this tube emits penetrating radiation known as X rays. The applied voltage (kV) and current (mA) determine respectively the penetrating power and the intensity of X rays. The energy and intensity are usually adjustable in X ray machines.

Gamma ray sources: Radioactive isotopes which emit gamma radiation, such as Iridium-192, Cobalt-60, Thalium-170 and Selenium-75 are used for non-destructive testing in the same way as an X ray machine. Like X rays, gamma rays are also electromagnetic radiation. These two types of radiation differ only in their wavelength and the way they are produced. Gamma rays are emitted during the disintegration of an excited and unbalanced atomic nucleus.

Unlike X rays, the energy of gamma radiation sources cannot be altered. It depends upon the nature of the radioactive source and is fixed for a particular source. The intensity is also not controllable for a given source, since it is impossible to alter the rate of disintegration.

2.1.2. Radiation attenuation in materials

When X or gamma rays pass through the specimen, the intensity reduces due to attenuation of the rays. The intensity of the rays coming out of the specimen is given by:

$$I = I_o e^{-\mu t}$$

Where
- I = intensity of the transmitted radiation
- I_o = intensity of the incident radiation
- μ = linear absorption coefficient of the material through which radiation passes. It depends on the energy of the radiation and the atomic number of the material.
- t = thickness of the specimen

The above equation is true for narrow beam geometry. However, broad beam geometry is usually encountered in practical applications. For broad beam geometry:

$$I = B\, I_o e^{-\mu t}$$

Where:
- B is called the "Build-up factor".

B represents the contribution of the scattered radiation.

The half value layer (HVL) is used for practical purposes. The value of μ is connected with HVL by the relationship:

$$\mu = 0.693/HVL$$

2.1.3. Geometric factors

X ray tubes and radioactive sources always produce a certain fuzzy image of the specimens because of their finite dimensions. The nonclear frame (or partial shadow surrounding) of the specimen is technically known as the "penumbra" or "unsharpness". It has an isometric form. The value of geometric unsharpness (U_g) depends on the size of the source (s), the thickness of the specimen (d) and the source to film distance (SFD). The general formula relating these parameters is as follows:

$$U_g = s\, d / (SFD-d)$$

It is desirable to keep U_g to minimum in order to detect fine defects.

2.1.4. Films/Detectors

The films are coated with a sensitive emulsion of silver bromide on both sides of the cellulose triacetate or polyester base. The size of silver bromide particles decides the speed of the film. The finer the particles, the slower will be the speed of the film. Fast films give lesser resolution than the slow films. However they save exposure time.

Hence, medium speed films with medium contrast and speed are usually employed, unless otherwise required. For X ray energies higher than about 120 kV, the film is used in conjunction with foils of lead called 'intensifying screens'. These screens increase the density on the film and thus reduce the exposure times. They also prevent long wave length scattered radiation reaching the film. Such scattered radiation reduces the contrast.

There is a trend to replace radiography film by non-film type radiation detectors. Digital radiography uses radiation detectors for real time radiographic imaging. There is a wide range of such detectors, from the simplest fluorescent screen to linear diode arrays. Digital radiography is complementing film radiography for on-line NDT inspection. The resolution provided by X ray films is still the best in comparison with non-film digital detectors. When needed, X ray films can now be used to discover defects as small as 10 μm in size.

2.1.5. Optical density

The film density D is the major parameter characterizing the quality of the radiographic film. It is expressed as follows:

$$D = \log_{10} I_o / I_t$$

Where

- D = is the density of radiographic film
- I_o = is the intensity of incident radiation
- I_t = is the intensity of transmitted radiation

2.1.6. Quality of radiographs

Any radiographic image is characterized by three parameters:

- the optical density
- the contrast
- the resolution

Optical density is determined by the film speed and exposure time for a given specimen. Contrast on a film is governed by the specimen, radiation and film properties. Resolution of the film image is mainly influenced by the film quality and geometrical unsharpness, although the energy of radiation also has some effect at the higher energies. Overall, the combined effect of all three parameters decides whether the film image is capable of revealing intended flaws. For verifying its capability, a device called an image quality indicator (also called a penetrameter) is used.

2.1.7. Image quality indicator (IQI)

As a check on the quality of the radiograph and the technique adopted, an IQI is used during the exposure. The IQI is placed suitably on the test material and the exposure is taken. Varieties of IQIs are recommended by different standards and are used in industrial radiography. The most commonly used penetrameters are:

- The step type with hole - BIS (Indian)
- The wire types – DIN, ISO and GOST (Russian)
- The plate with holes — ASTM and AFNOR (different designs)
- The Japanese standards JIS use an additional device called a Contrast-meter.

2.2. PIPE TANGENTIAL RADIOGRAPHY

Pipe corrosion and deposits are closely related to pipe wall thickness. The most important parameter in a pipeline to be monitored and measured is the wall thickness. Only the radiographic method assures pipe inspection without costly removal of insulation material during operation of the plant. An additional advantage is that radiography can even be applied in high temperature environments. Radiographic evaluation of the corrosion/deposit rates in pipes (insulated or not) is an effective NDT method. There are several radiography testing techniques applied in industrial manufacturing and civil engineering structures. Tangential radiography is a technique of choice for corrosion and deposits evaluation in pipes. It provides a more complete and accurate picture of the pipe thickness and defects.

The radiographic tangential method for corrosion and deposit evaluation in pipes was the major subject of the CRP. Tangential radiography (or profile radiography) provides a more complete and accurate picture of the metal thickness and defects. Tangential radiography applies X or gamma rays through the insulation at an angle tangential to the edge of the pipe (Fig. 4).

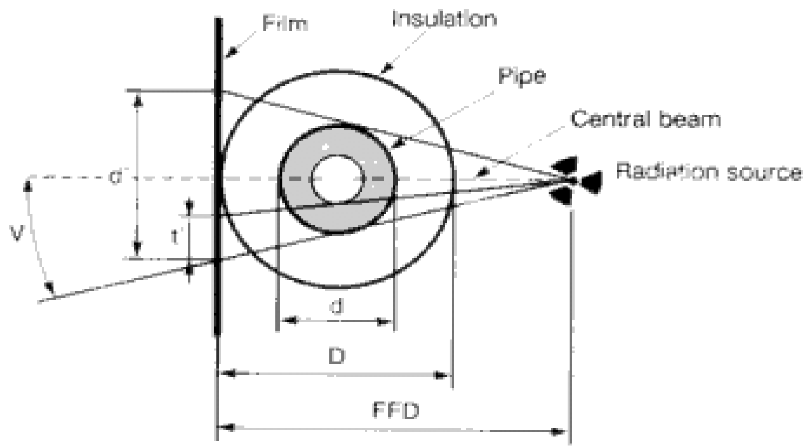

FIG. 4. Principle of radiography.

Tangential radiography is the most convenient technique for measuring the remaining wall thickness of corroded pipes and for assessing the thickness and location of deposits. In this technique, a view of the pipe longitudinal section, including a profile view of the pipe wall, is projected on to a film, enabling direct measurement of the pipe wall thickness. Proper geometric relations must be established between the source, the specimen and the film so that the radiography image can be properly interpreted.

The radiation source mostly used in tangential radiography is the radioisotope Ir-192, especially for small diameter pipes. For thicker pipes, or pipes with outer diameters (OD) greater than 250 mm, the radioisotope Co-60 is often used. Pipe tangential radiography is normally not carried out with X rays or Se-75 due to their soft energies. The tangential imaging requires harder gamma radiation, because the tangential configuration leads to greater material thicknesses to be penetrated by the rays.

2.2.1. Tangential radiography and wall thickness assessment

The tangential radiography set-up for a pipe is presented in the Figure 5. The figure shows the apparition of two walls with the presence of different types of corrosion (deposits, uniform corrosion etc.). Once the gamma ray shoot has been applied and the film developed, the interpretation of the image and the evaluation of the tube thickness have to be performed.

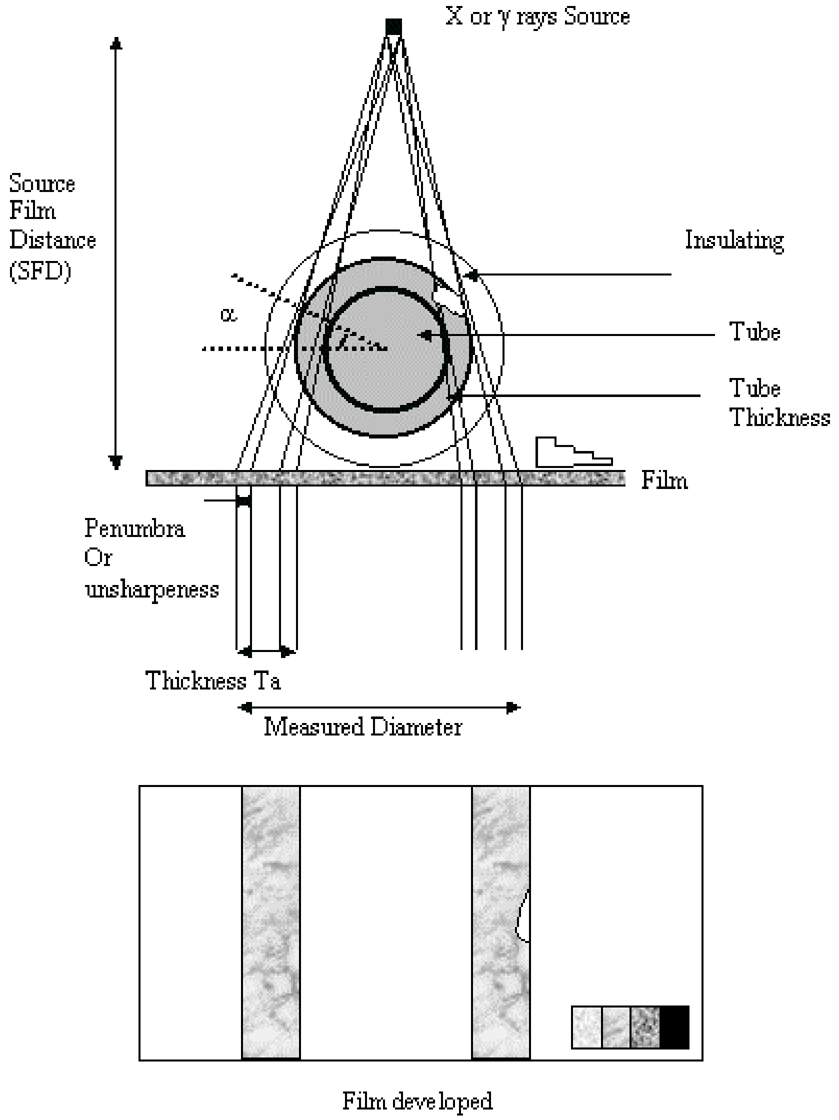

FIG. 5. Tangential radiography set-up.

Determination of source-film distance: The source is placed far from the tube in order to project the two walls of the tube on the film. Because of the finite dimension of the radioactive source, the penumbra or unsharpness appears on the film. The value of geometric unsharpness U_g is given by the following equation:

$$Ug = \frac{s(0.5OD + d)}{SFD - (0.5OD + d)}$$

Where :

- SFD is the source-film distance
- Ug is the geometric unsharpeness
- OD is the external diameter of tube
- d is the insulation thickness
- s is the source size.

The equation shows that unsharpeness is inversely proportional to the source-film distance. To decrease the fuzzy effect, a relatively long source-film distance is required. The experience has shown that the optimal SFD lies within 8 – 10 tube ODs.

Determination of radiation exposure angle (α): By changing the SFD, the operator can arrange the tube position to project suspected defects on to the film with optimum resolution and contrast parameters. The relationship that determines the radiation exposure angle α, as shown in figure 5, is given by:

$$\alpha = \frac{\cos^{-1}(0.5OD)}{SFD - 0.5OD}$$

This angle is a function of the SFD and OD of the pipe.

Geometrical evaluation of the real pipe thickness: The measured thickness of pipe wall on the radiogram (Ta in fig. 5) is not exactly the real pipe wall thickness Tw due to the fuzzy effect. The accurate evaluation of the real pipe wall thickness is very important to determine the remaining pipe thickness and consequently to assess the corrosion or deposit rate. The relation between Tw and Ta is given by the formula:

$$Tw = Ta\frac{SFD - 0.5OD - d}{SFD}$$

The difference between Tw and Ta (the so-called "magnification correction") is significant when the SFD is relatively short. This correction has to be taken account for obtaining high accuracy. The encountered problems that affect the accurate evaluation of the real pipe wall thickness are the following:

- The effect of geometric projection; the film is not flat but plated on the tube
- The fuzzy effect on pipe edges
- The pipe edge limits are subjective to the operators' experience

Maximum transmitted thickness: When using the tangential radiographic method for pipe inspection the gamma rays penetrate different thickness of the pipe projection. The minimum transmitted pipe thickness is zero, which happens at the pipe tangential points. The maximum transmitted thickness is the pipe inside diameter. This significant difference in the transmitted thickness brings high differences in film exposure. Because the thinnest portion will cause too dark an image (burn-off) and the thickest portion will cause too bright an image, the selection of the optimum source energy and exposure parameters is very important. Gamma rays penetrate different metallic thicknesses depending on their energies. Table I provides typical values of maximum transmitted thickness for different X ray and gamma radiation sources. This table helps in the selection of a suitable gamma source for optimum pipe wall inspection.

TABLE I. MAXIMUM TRANSMITTED THICKNESS

<table>
<tr><td>Pipe OD, mm</td><td>25</td><td>50</td><td>75</td><td>114</td><td>159</td><td>219</td><td>426</td><td>630</td></tr>
<tr><td>Pipe wall thickness, (Tw) mm</td><td>4</td><td>4</td><td>6</td><td>10</td><td>14</td><td>20</td><td>14</td><td>20</td></tr>
<tr><td>Max. transmitted thickness, mm</td><td>16</td><td>28</td><td>40</td><td>62</td><td>90</td><td>126</td><td>150</td><td>270</td></tr>
<tr><td rowspan="4">Applicable radiation source</td><td colspan="4">X rays</td><td colspan="4"></td></tr>
<tr><td colspan="6">Se-75, Ir-192</td><td colspan="2"></td></tr>
<tr><td colspan="4"></td><td colspan="4">Co-60</td></tr>
<tr><td colspan="4"></td><td colspan="4">Liner accelerator</td></tr>
</table>

The theoretical curve for intensity versus pipe cross section is shown in Fig. 6. The figure presents a typical line plot in tangential radiography of the optical density across the tube diameter. The real pipe wall thickness can be measured between the inflection points a and b.

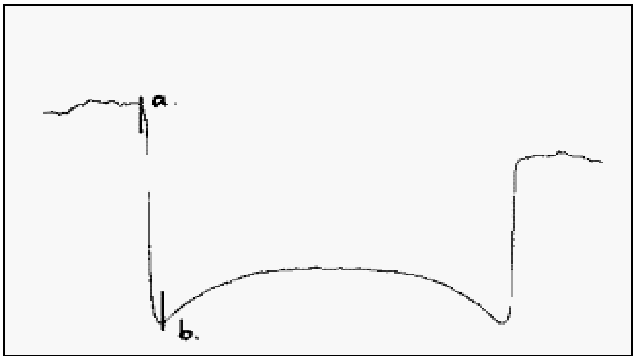

FIG. 6. Typical line plot in tangential radiography showing optical density across the tubes diameter. The real pipe wall thickness can be measured between a and b.

2.3. PIT DEPTH EVALUATION BY THE DENSITY MEASUREMENT METHOD

A search for isolated or spatially distributed corrosion (e.g. pitting) is possible in tangential radiography. In this case, the film is evaluated in the area of nearly uniform optical density between the two intensity peaks. When a pit is just located on a side tangential wall, its size can be easily measured by tangential radiography. The pit distribution, and its size, will be clearly shown on the radiogram. Its depth can be evaluated by using a density-thickness reference curve.

3. THE COORDINATED RESEARCH PROJECT (CRP)

3.1. SCIENTIFIC BACKGROUND

As seen in Chapter 2, it is possible to assess the remaining wall thickness using the radiography technique. The principles of corrosion/deposit measurement/monitoring by means of tangential, film based, radiography have been known for a long time. Several thousands of NDT measurements are performed annually by well-established NDT serving companies. Cost effective tests have been reported and applied for both insulated and non-insulated pipes in power stations, refineries, petrochemical and chemical plants. Successful in-service inspection of deposit/scale in water desalination pipelines and urban gas installations has also been reported.

Corrosion attack of pipe walls covered by deposit layers has also been detected by the radiography technique. In spite of this experience, however, there are no standardized and universally recognized protocols and recommended practices for these particular radiographic tests. For instance, typical test arrangements (two walls — one image, two walls — double image techniques), as well as geometrical condition of the tests, minimal number of exposures, source/energy selection, and interpretation principles, are not specified.

Costly mistakes can occur consequently in the hands of an inexperienced operator. Lack of standard and objective criteria for evaluation of the test results may cause under or over estimation of the remaining wall thickness of the pipe, which is risky and costly, with an unnecessary increase of the shutdown time of the installations.

It happens that a lack of reliable and well verified radiographic testing (RT) protocols discourages NDT laboratories from proposing services to potential customer/end-users in the industry; this in spite of well identified needs in such areas as determination of deposits and under-deposit corrosion in sea water desalination pipelines, corrosion/erosion attack in bends, corrosion in insulated as well as non-insulated hot pipes in oil refineries, fossil plants, etc.

During the last two decades the IAEA sponsored three large regional technical co-operation programmes in the field of NDT. As a result of regional projects implemented in Latin America, Asia and Africa including dozens of national bilateral programmes, thousands of NDT specialists at levels 1, 2 and 3 have been trained in basic and advanced NDT methods. Moreover, NDT laboratories equipped with basic NDT units have been set up.

The CRP on Validation of Protocols for Corrosion and Deposits Determination in Small Diameter Pipes by Radiography (CORDEP) addressed the needs of the laboratories and took advantage of the infrastructure already available. This first-ever CRP in the NDT field is aimed at developing radiographic protocols and instructions for identification and measurement of the corrosion attack and deposits in pipes across insulation in industrial installations during operation (on-line and in maintenance).

The CRP also addressed the needs of end users in terms of developing reliable and appropriate NDT measurement protocols which should refer to general requirements of international standards, (e.g. ISO 5579 — RT basic rules, ISO 1106/3 — RT circumferential weld in pipes, etc.) with full implementation of recognized quality assurance methodologies.

The general scope of the CRP covered radiographic measurements of corrosion and deposits in straight pipe and bends made of carbon or stainless steel from the petroleum and gas industry or water installations, corroded/eroded on the outer or inner surface without insulation or having thermal or bituminous insulation. The results of RT were verified by ultrasonic measurements and by destructive testing when appropriate.

In particular, in the field of corrosion evaluation, the CRP has developed protocols for:

- *Full inspection*: Detection, localization and measurement of non-identified corrosion attack across the pipe wall and/or insulation by radiography on the whole perimeter of pipe by the double wall technique.

- *Local inspection*: For the selected areas only, e.g. radiographic measurement of the remaining wall thickness in the curved pipes (bends) across the insulation using the tangential radiography technique.

Radiographic evaluation of deposits encompassed the determination of the deposit geometry (flat, concentric, eccentric) and thickness. It included the evaluation of the corrosion attack (if any) under the deposit.

3.2. IMPLEMENTATION OF THE CRP

It was decided to adopt a round robin format for the CRP, in which the same set of sample would go to different participating countries for testing.

3.2.1. Preparation of test pieces

The participants agreed to prepare the following types, numbers and dimensions of the test pieces.

- Number of test pieces: 3 pieces per participating laboratory (country)
- Diameter of test pieces: 25, 50, 100 and 150 mm
- Thickness: 4 – 8 mm
- Length: 300 mm (pipes), 450 mm (bends)

The detailed distribution of the test pieces between participating laboratories is given in Table II.

The specimens were original (natural) and fabricated. Original in this case means pieces of pipes in operation, while the fabricated pipe tubes were manufactured according to test piece procedures. The steel pipes and bends were both insulated and without insulation, with regular corrosion/ erosion and/or pits on the inner and outer diameters (under the insulation). Some of the specimens had deposits inside the pipe. All fabricated specimens (as well as some natural) were identified as confidential. It means that the position, character and size of imperfection(s) were known to the owners of the specimen only.

For some natural specimens the localization of the corrosion attack (or erosion) were declared and indicated on the surface of specimen by the owner of specimen. All specimens were covered at the ends (spot welding) in order to keep imperfections invisible. Table III gives the details of the test pieces from all the countries.

TABLE II. DETAILS OF SPECIMENS.

COUNTRY	SPECIMEN DIAMETER AND NATURE F – fabricated O – original				INDUSTRY
	25 mm (1")	50 mm (2")	100 mm (4")	150 mm (6")	
Asia group:					
China	O	O	F, F	---	Power,
India	---	FF	O	F	Petrochemistry
Rep. of Korea	---	F, F,F	---	---	Petrochemistry
Malaysia	---	O, O, F	---	---	Oil & Gas
Sri Lanka	O	O	---	O	Oil
Mediterranean group:					
Algeria	---	---	O	O	
France		O	O	O	
Syria	---	---	O, F, F	---	
Tunisia	---	O	O	O	
Turkey	---	O, F, F (1 with deposit)	---	---	
Latin America group: (Costa Rica)	-	O, F	-	-	Power, Petrochemistry

TABLE III. DESCRIPTION OF TEST PIECES

Country of origin	Specimen No.	Outside diameter O.D. (mm)	Nominal thickn. N.T. (mm)	Length L, (mm)	Type of specimen
Tunisia	TUN3	150	4		
	TUN2	100	6.5		
	TUN1	60	4		
Syria	SYRO1	110	4	300	Elbow
	SYR F2	110	4	300	Insulated pipe
	SYR F1	110	5	300	
Turkey	TUR-ORG P3	60	3.5	300	Straight pipe
	TUR-FAB-E2	60	4		Bend
	TUR FAB-P1	60	4	300	Straight pipe
Algeria	ALG2	168	6	230	Bend
	ALG1	100	4	488	Bend
France	FRA3	168	8	320	Straight pipe
	FRA 1	60	4	300	Straight pipe
	FRA 2	114	6		
Malaysia	M-ORG-1	69	7.4	350	Straight pipe
	M-ORG-2	69	7.4	350	Straight pipe
	M-FAB-3	69	7.4	395	Straight pipe
India	IND-FAB-1	50	7		Insulated bend
	IND-FAB-2A	74	8	200	Insulated pipe
	IND-ORG-2B	90	7	200	Insulated pipe
	IND-FAB-3	168	6	200	Insulated pipe
Sri Lanka	SRL-ORG -1	45	5	400	Insulated pipe
	SRL-ORG-2	65	3.9	135	Bend
	SRL-ORG-3	120	6.0	360	Pipe
China	PRC-FAB-1	114	8		Insulated pipe
	PRC-FAB-2	105	6		Insulated elbow
	PRC-ORG-1	50	4		Insulated pipe
	PRC-ORG-2	30	4		Insulated elbow
Rep. Korea	KOR-FAB-1	60.6	4	300	Straight pipe
	KOR-FAB-2	60.6	5.6		Insulated pipe
	KOR-FAB-3	60.6	4		Elbow
Costa Rica	CR.ORG-1	60	5.5	190	Straight insul. pipe
	CR.FAB-1	60	3.1	260	Straight pipe

3.2.2. Test methods and techniques

X ray and gamma ray radiography using films were chosen by the participants. Rapid, instant and real time radioscopy testing (e.g. for preliminary searching for corrosion attack) was not included in the programme due to limited availability of related specialized equipment in the participating laboratories. In principle, the tangential radiography was the main subject of the CRP.

The complementary NDT methods such as the ultrasonic testing, as well as destructive testing and metallography when required, were applied for verification of the RT results (validation).

3.2.3. Test procedure (Protocol)

RT instruction (producing of radiographs)

For radiographic testing, the general standard ISO 5579 was adopted and applied for the round robin test, with necessary modifications.

Test extent

As the defects were not known to the testing laboratories, these specimens were inspected first in 100 % (so-called "full" test), on the whole perimeter of pipe. At this stage imperfections were detected and locations determined. Then, during the second stage, imperfections were characterized and measured (dimensioning).

Interpretation of radiographs

The interpretation of the results was done by manual (analogue) method. However, those who had the technology available have carried out digitization of the films and extracted the results digitally, in addition to the analogue method.

3.2.4. Round robin test (RRT)

In order to avoid excessive duration and cost of transportation of specimens, three different cycles of sample transfer were decided upon.

ASIA group:

China → Malaysia → Sri Lanka → India → Rep. of Korea

Mediterranean group:

Turkey → Syria → Tunisia → Algeria → France

Latin America group: The RRT was performed within Costa Rica between NDT laboratories working inside the country by rotating the samples among the four listed laboratories.

ITCR → COOPES → RECOPE → ICE

With each specimen the following documents were sent (first by the owners and then from country to country):

A. Specimen documents; sketches with:

- Outer diameter
- Nominal thickness of wall
- Thickness of insulation (if any)
- Material pipe

- Welding place (if any)
- Radius (for bends)
- Specimen code
- Specimen label with places and dates of consecutive tests

B. Test documents:

- Localization of the imperfection/zone(s) to be inspected. (Only for some Original, and not Confidential Specimens.)
- Test arrangement (without focus-to-film distance and marking scheme): General arrangement only as shown in the RT Instruction form (only for information, not obligatory to follow in the next laboratory)
- Source of radiation used (for information only)
- Examination instruction and test report, prepared in each laboratory for each specimen, were kept confidential, for validation purposes.

Validation documents produced during the RRT and kept confidential in each laboratory for validation process were the following:

- examination instructions
- test reports and radiographs

The test report contained:

- Name of laboratory
- Report date and number
- Number of examination instruction
- Specimen identification number (owner country code and number)
- For corrosion/erosion: nature of imperfection (regular, pit), mapping (geometrical form, orientation, length, width) and minimal remaining wall thickness.
- For deposit: form, maximum thickness

Validation procedure

Participants from China, France, India, Rep. of Korea and Turkey prepared the validation procedure which included the method of comparison of RRT results (of individual reports and analogue readings)

4. EXPERIMENTAL PROCEDURE

This Chapter summarizes the procedure adopted by the participating countries for assessing the minimum wall thickness remaining in the RRT specimens. As the methods adopted were found satisfactory in assessing the remaining wall thickness to a good accuracy, the procedure in this Chapter can be treated as the protocol of testing.

4.1. SELECTION OF METHOD

Broadly two radiography methods are available for wall thickness measurement.

The density transmission method applied in the double wall double image (DWDI) configuration is the classical density measurement radiography where the gamma rays penetrate through two walls of the pipe tube placed between source and film. In this respect it is a simple radiography technique where source and film are outside the pipe tube. DWDI radiography is commonly used for checking defects in pipes. For small size pipes usually two exposures are taken by rotating the pipe through 90 degrees in order to avoid the overlap of the top and bottom defects if present, and to better inspect the pipe from all sides. On the side of the pipe, a stepped block or wedge is kept for comparison of density with the defect density. This block will contain thicknesses ranging from T to 2T where T is the single wall thickness of the pipe. However, this method is useful only for such pipes which have no insulation or the insulation is a non-metallic thin layer with negligible radiation absorption. The gamma ray source could be placed inside the pipe as well (so-called single wall radiography) but this technique is not performed in practice for small diameter pipes.

The other method is tangential radiography, which is able to measure wall thickness on two sides of the pipe in the same exposure. The radiation source is placed above the pipe being radiographed tangentially rather than at centre of the pipe. Shading of the tangential radiograph between the two sides allows observation of local corrosion, erosion, deposits and pitting. The tangential paths of radiation within the pipe walls project the edge location, and pipe thickness can be evaluated with high accuracy. This is a very accurate method to measure the actual pipe wall thickness. In the tangential radiograph the viewer can see thinning on the bottom of the pipe, process material deposit in the bottom of the pipe, and other defects related to corrosion and deposits. The amount of detail obtained by tangential radiography allows for inspection and evaluation of corrosion and deposits which are the major problems in plant life assessment.

All the eleven CRP participants' NDT laboratories adopted the tangential radiographic method for the 29 pipes under study. This accounts for 150 radiographic exposures. In addition some pipes where the density measurement method was applicable were performed by the DWDI method. This accounted for another 35 exposures. Pipes without insulation were also subjected to the tangential radiography method by some CRP participants.

The tangential radiography method requires that the location of interest lies exactly at the tangent projection. This needs *a priori* knowledge of the defect. In other words the tangential method has to be preceded by the DWDI exposures to determine the location of the defects. The process of finding the location of the faults using DWDI often demands a large number of exposures. This can become frustrating and time consuming. One of the CRP participating countries has proposed a technique by which the location of the least wall thickness can be pinpointed accurately in only two DWDI exposures. After finding that location, the third exposure can be the tangential exposure for determining the wall thickness.

4.2. TECHNIQUE PARAMETERS

4.2.1 Energy

Participants in the RRT have applied X rays as well as gamma rays. For gamma rays, the Ir-192 radioisotope was used (activity 2-5 10^3 GBq). The gamma ray source was used for 42 pipes in the Asia group and 28 pipes in the Mediterranean group. Similarly, X rays with different energies were used respectively on 46 and 15 pipe tests.

The general guideline was that the DWDI radiography has to be performed using X rays, whereas gamma rays are more suitable for tangential exposure. However, some countries carried out tangential radiography using X rays due to non-availability of the gamma ray isotope.

A typical tangential radiography set-up applied in almost all CRP participants' laboratories for insulated pipes is shown in figure 7.

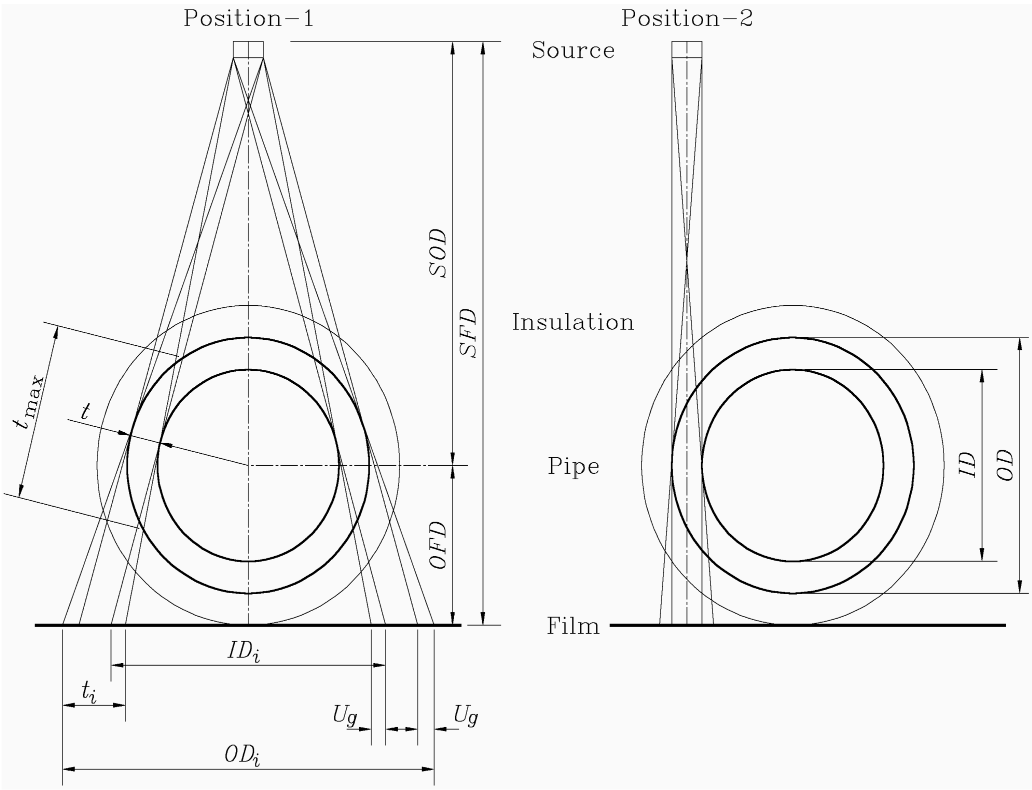

FIG. 7. Test arrangement for tangential radiography.

Where :

- SFD is the source film distance
- OFD is the center tube film distance
- SOD is the source center tube distance
- Ug is the geometric unsharpeness (or penumbra)
- ODi is the external diameter of tube
- IDi is the internal diameter of tube
- t_i is the insulation thickness

4.2.2. Film screen

Different types and speeds of films were used with appropriate front and back intensifying Pb screens.

4.2.3. Image quality indicator (IQI)

Selection of IQI was performed for the tangential radiography. It was done as per known codes, based on the 2% criterion. However for tangential radiography it is not a unique choice. Some laboratories have taken the tangentially traversed thickness as the thickness radiographed and placed the IQI on an equivalent block by the side of the pipe. Some others have chosen a penetrameter based on a thickness of half the tangential path length as the average thickness radiographed.

For the purpose of standardization of the technique, both the approaches were acceptable. The purpose of an IQI is only to verify and compare techniques and not to assure the defect detection. From that point of view the placement of an IQI at any place or any thickness is acceptable.

4.3. METHOD OF EVALUATION

The DWDI technique exploits the density of the zone of minimum wall, matching it with the density of the stepped wedge kept nearby. Optical densities were measured using manual densitometers. The density at the defect location was compared with that on the step block. From here the nearest matching step can be taken for finding the equivalent wall thickness.

Alternatively, a calibration curve can be drawn between densities and step thickness (Fig. 8). Wall thickness can be found by reading out against the observed density.

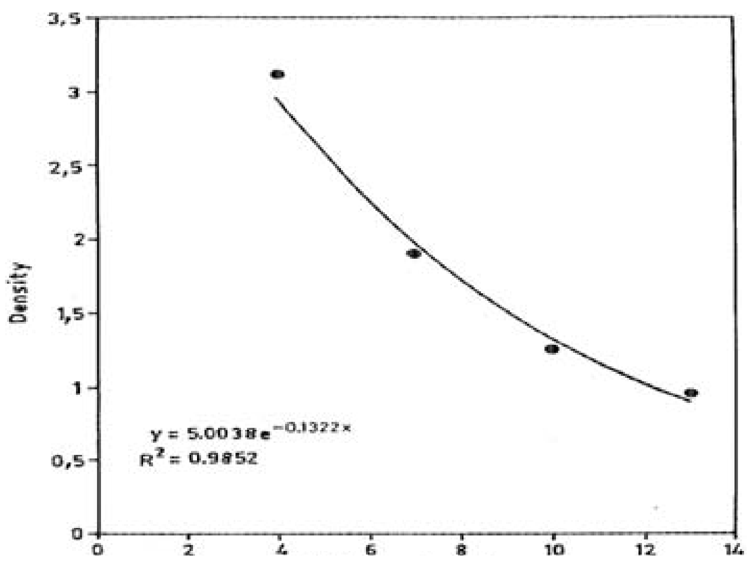

FIG. 8. A typical thickness density calibration curve for the DWDI technique.

For the gamma ray tangential technique, evaluation of the least wall thickness was done by using calipers or optical scales. Evaluation results were tabulated in a standardized format by each participating country.

4.3.1. Digital methods

One laboratory carried out a computer aided evaluation. It used a flat bed scanner with transparency adapter as well as cameras for digitizing the image. For this purpose films are illuminated from behind and a camera is focused on the full image. If the camera is an analogue type, the output is taken to hardware fitted in the computer, called the frame grabber, which creates a digital image. Alternatively a commercially available digital camera can be used. Here the digitizing was done on-board and data were transferred to a PC. The resolution of the digital camera can be varied as required, but in the case of an analogue camera it is pre-determined by the grabber card.

After digitization, the images were evaluated on a PC in different ways as follows:

a) A simplest way was to count the number of pixels in a sound wall as well as in the corroded wall. The former gave the calibrated dimension of the pixel in absolute length units that was used to assess the thickness of corroded wall. This eliminates the need to know the magnification used while taking the radiograph. Instead of absolute measurement, the remaining wall was also assessed as the percentage of the intact wall.

b) If software is available to scan across a given feature and produce a profile plot of density, the counting of pixels can be made easier. It is necessary to identify two boundaries of the wall on the plot and then to find the distance between them in terms of pixel count.

c) To highlight clearly the feature of interest, a digital subtraction technique can be used. In this case an image with a defect is subtracted from the sound image. It is essential that the two images are superimposed perfectly onto each other for this purpose. Different techniques can be used for this, but it remains an art rather than a science.

5. RESULTS AND DISCUSSION

5.1. RESULTS

Results obtained by all the CRP participants for all the pipes in their respective groups were discussed in a joint meeting. Evaluation was done considering the success rate in detection of defects and finding their nature as well as in assessing the minimum remaining wall thickness. The CRP results are presented in two tables. The Table IV shows results obtained by NDT laboratories in the Asian group and Table V presents the resultants of the Mediterranean group.

The following is a summary of the results with respect to three important parameters:

- Detection of defects: All defects (artificial and natural) were found by all CRP participants in their respective group, so far as they used the same conditions.

- Thickness loss caused by corrosion phenomena was measured with a maximum deviation of 1.5 mm (for two pieces) and 1 mm maximum for the rest of the pieces (25 pieces). The best accuracy achieved for thickness loss measurement was 0.5 mm (The accuracy was considered the maximum deviation, i.e. the difference between the maximum and minimum values. The relative error was found to be between 5 and 15 %).

- Defect size measurement: the maximum deviation on the measurement of defect dimensions (other than depth) was 5 mm on one piece and 2 mm for the other test samples (the relative error was estimated to be 10 -20 %).

Costa Rica results: Due to the distant location Costa Rica was not a part of the RRT. Instead, four NDT laboratories inside Costa Rica performed examination of samples.

All the defects in the first sample specimen and the deposit in the second one were successfully detected by the four Costa Rica laboratories. The thickness loss caused by erosion/corrosion phenomena was measured for the two pipes with a maximum deviation of 1 mm (relative error of 10%). The deposit in the second specimen was measured with a maximum deviation of 2 mm (relative error of 20%).

TABLE IV. CRP RESULTS OBTAINED BY NDT LABORATORIES IN ASIA

Specimen No.	Specimen Details	Test Parameters	Minimal Thick T_{min} (mm)	Remarks
SRL-ORG-1	Insulated Pipe. OD = 45mm, N.T.= 5 mm	X ray; kV: 250, mA: 4, SFD= 635mm	2.2	Uniform corrosion
SRL-ORG-2	Bend OD = 65mm, N.T. = 3.9 mm	X ray; kV: 250, mA: 4 , SFD= 635mm	1.6	High corrosion
SRL-ORG-3	Pipe OD = 120 mm, N.T. = 6.0 mm	X ray; kV: 150, mA: 5, SFD= 260 mm	2.5	High corrosion
M-ORG-1	Pipe OD = 69 mm, N.T. = 7.4mm	X ray; kV: 150 , mA: 5, SFD= 350 mm	2.2	Deposit / scale
M-ORG-2	Pipe OD = 69 mm, N.T.= 7.4 mm	X ray; kV: 150, mA: 5, SFD= 350mm	6.0	Light corrosion

Specimen No.	Specimen Details	Test Parameters	Minimal Thick T_{min} (mm)	Remarks
M-FAB-3	Pipe OD = 69 mm, N.T. = 7.4 mm	X ray; kV: 150 , mA: 5 , SFD= 350 mm	3.0	Light Bend/patch
PRC-ORG-1	Insulated straight pipe OD = 50 mm, NT = 4 mm	X ray; kV: 250, mA: 5 , SFD= 625mm	2.5	Uniform natural corrosion
PRC-ORG-2	Insulated bend OD = 30mm, NT = 4 mm	X ray; kV: 250, mA: 5, SFD= 625mm	2.8	Uniform natural corrosion
PRC-FAB-1	Insulated straight pipe OD = 114mm, NT = 8 mm	X ray; kV: 300, mA: 4, SFD= 635mm	3.8	Pitting
PRC-FAB-2	Insulated bend OD = 105mm, NT = 6 mm	X ray; kV: 250, mA: 5, SFD= 625mm	4.6	Uniform corrosion
KOR-FAB-1	Pipe OD = 60.6mm, N.T. = 4 mm	X ray; kV: 250, mA: 5 SFD= 625mm	1.5	Pitting/ Corrosion
KOR-FAB-2	Insulated pipe OD = 60.6mm, N.T. = 5.6mm	X ray; kV: 300, mA: 4, SFD= 635mm	3.5	Through hole
KOR-ORG-3	Elbow OD = 60.6mm, N.T. = 4 mm	X ray; kV: 300, mA:4, SFD= 635mm	1.6	Corrosion/ through hole
IND-FAB-1	Elbow with insulation OD = 50mm, N.T. = 7mm	X ray; kV: 250, mA: 5, SFD= 625mm	5.2	Ground patch
IND-FAB-2A	Pipe with insulation OD = 74mm, N.T. = 8mm	X ray; kV: 300, mA: 4, SFD= 635mm	4.6	Corrosion
IND-ORG-2B	Pipe with insulation OD = 90mm, N.T. = 7mm	X ray; kV: 300, mA: 4, SFD= 635mm	2.4	Local corrosion
IND-FAB-3	Pipe with insulation OD = 168mm, N.T. = 6mm	X ray; kV: 300, mA: 4, SFD= 635mm	4.1	Milled notches

TABLE V. CRP RESULTS OBTAINED BY MEDITERRANEAN NDT LABORATORIES

Specimen No.	Specimen details	Nature of defects	Test Parameters	Results
TUR-FAB-P1	OD = 60 mm NT = 4 mm L =300 mm	Long and circular notches, drilled hole and partially deposit	Source: X ray Int.:5 mA Focus: 3 mm Volt: 180 kV SDF: 700 mm Exp. Time: 4 min. Dev.: 5 min. at 20^0C	Wall thickness: 4 mm Notch depths: Long notch: 2.5 mm Circ. notch: 2 mm Hole: 2 mm Deposit.: 2 min., 6 max.
TUR-FAB-E2	OD 0 60 mm NT = 4 mm Elbow 90^0C	Artificial wall degradations (2 pieces)	Source: X ray Int.:5 mA Focus: 3 mm Volt: 200 kV SDF: 700 mm Exp. Time: 5 min. Dev.: 5 min. at 20^0C	Remaining wall at cylinder hole: 0.5-1 mm Wall degraded.: 2 mm

Specimen No.	Specimen details	Nature of defects	Test Parameters	Results
TUR-ORG-P3	OD = 60 mm NT = 3.5 mm L = 300 mm	Natural pits	Source: X ray Int.:5 mA Focus: 3 mm Volt: 160, 180 kV SDF: 700 mm Exp. Time: 4, 6 min. Dev.: 5 min. at 20^0C	Wall thickness: 3.15 mm (form density meas. tech) Pits depths: 1.2 mm, 1.3 mm, 1.2 mm
FRA1	OD =60 mm NT = 4 mm L = 300 mm	Corrosion	Source: X ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 120 kV SDF: 700 mm Exp. Time: 2,3,4 min. Dev.: manual t =5 min.; T = 20^0C	Pit.Dia.: 6 mm

FRA 2	OD=115 mm NT = 6 mm L = 300mm	3 corrosion pits and circular notches (artificial)	Source: X ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 140, 150 kV SDF: 700 mm Exp. Time: 2 ,3 min Dev.: manual t =5 min.; T = 20^0C	Wall th.: 6 mm 3 pits: ϕ6, ϕ10, ϕ10
FRA3	OD= 167mm NT= 6 mm L = 310 mm	2 corrosion pits and 3 half circular notches, half-ring	Source: X ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 150, 160, 180 kV SDF: 700 mm Exp. Time: 3, 4 min. Dev.: manual t = 5 min.; T = 20^0C	Pit dia: 10 mm Wall thickness: 6 mm
ALG1	OD =100mm NT = 4 mm L: Bend	1 corrosion pit and 1 circumferential notch+1 half. circ. Notch	Source: X ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 120, 140 kV SDF: 700 mm Exp. Time: 2.5 min. Dev.: manual, 5 min. at 20^0C	Pit depth: 5 mm Wall th.: 4 mm
ALG2	OD=230 mm NT = 6 mm L = 230 mm	Longitude & circumflex. notches	Source: X ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 120, 140 kV SDF: 700,1500,2000 mm Exp. Time: 2.5 min. Dev.: 5 min. at 20^0C	Wall thickness: 6 mm Length of notches: 60, 60 and 75 mm Width: 2 mm

Specimen No.	Specimen details	Nature of defects	Test Parameters	Results
SYR O1	OD=114 mm NT = 4 mm L – bend 3 mm min. elbow	Randomly distributed small pits	Source: X ray Volt: 160, 180 kV Int.:5 mA Focus: 3 mm SDF: 700 mm Exp. Time: 4 min. Dev.: 5 min. at 20^0C manually	Remaining wall thickness: 3 mm minimal 4 mm. maximal
SYR F1	OD=110 mm NT = 5 mm L = 300 mm Straight pipe	3 artificial ID grooves, each circumferential	Source: X ray Volt: 180 kV Int.:5 mA Focus: 3 mm SDF: 700 mm Exp. Time: 2, 3, 3 min. Dev.: 5 min. at 20^0C manually	Remaining wall thickness: 2 mm min. 4.5 mm. max. Width of grooves: 63, 33 and 33 mm respectively.
SYR F2	OD=108 mm NT =4 mm L = 300 mm Straight pipe	3 artificial ID grooves,2 artificial OD grooves, each circumferential	Source: X ray Volt: 180 kV Int.:5 mA Focus: 3 mm SDF: 700 mm Exp. Time: 2 min Dev.: 5 min. at 20^0C manually	Remaining wall thickness: 2 mm min. 3.5 mm. max. Width of OD grooves: 25 and 20 mm respectively. Width of ID grooves: 52, 26 and 25 mm respectively
Unknown Sample	OD = 64 mm NT =3.5 mm L = 300 mm Straight pipe	General corrosion, pits, artificial deposit	Source: X ray Volt: 160, 170 kV Int.:5 mA Focus: 3 mm SDF: 700 mm Exp. Time: 5, 7 min., Dev.: 5 min. at 20^0C manually	Remaining wall thickness: 3.5 mm. overall General corrosion with randomly distributed pits. Artificial deposit including cracks centric hole

5.2. DISCUSSION

As the films used by CRP participants were of different brand/type due to availability, it provided a good comparison of performance of different types of films with respect to image quality. Though it is known that fine grain films give good definition and resolution, it could not be established that they are always the best choice for the purpose of measuring residual wall thickness.

As the technique of tangential radiography needs low contrast and slow films usually produce high contrast, the benefits derived from the grains can be lost in inaccuracy of the boundary marking on the image. In fact medium size grain films (so-called normal quality Class 3 films), which are not recommended in weld radiography, can be used in tangential radiography when pipes have thick insulation and when the exposure time needs to be reduced. This is because the tangential radiography is not a high sensitivity technique in any case. It was found that the accuracy in wall determination is not correlated with the best IQI sensitivity.

RRT results brought out certain other observations as follows:

- X rays were used for DWDI exposures and gamma rays for tangential exposures by most of the CRP participants' laboratories.
- Iridium-192 was found to be the most convenient radioisotope (within available radioisotopes) from the aspect of best image definition.
- The SFD of about 8 to 10 times the pipe diameter was appropriate to obtain a good image quality.
- For a better identification of the internal diameter (ID) extremities of the pipe wall, a higher film density of up to 4 (at the centre of the pipe) was required.
- Accurate estimation of the pit depth was difficult by tangential radiography. The main problem was the alignment of the pitting. However, whenever such alignment was correct the pit depth could be determined fairly accurately.
- It is difficult to determine accurately the depth of pits on the ID when there is a deposit present on insulated pipe unless a detailed calibration is carried out.
- Low energy X rays cause burn-off at the outside part of the pipe. An X ray filter in front of the window of the tube may help to decrease burn-off.
- The pipes with a gradual change in wall thickness pose a problem to both methods. In the tangential radiography technique a large number of exposures will be needed to locate the minimum wall. The DWDI radiography (density measurement method) gives only the average of upper and lower wall thicknesses, hence no estimation can be made about minima and maxima.

Sources of error

It was observed that inaccuracy in the determination of wall thickness depends on the following factors:

— In the tangential radiography technique:

- *Too much contrast*: This makes demarcation of boundary difficult.
- *Alignment*: If the spot of the least wall thickness is not exactly at the tangent location, but shifted by an angle, it gives an under-estimation.
- *Least count of the measuring device*.
- *Error in magnification calibration*: To avoid this, it has been suggested to place an object with known width and higher absorption coefficient near the pipe while radiography is carried out. As the true size of the object is known, the dimension of the feature can be found out.

— In the DWDI radiography technique:

- *Too little contrast*: The full step wedge will cover only a small density range. Comparison of density on the spot and the step may look close by, even if it is not so.
- *Reference block positioning*: Position of the step reference block is important in order to avoid any image distortion and to observe the image magnification. Additionally, the radiation intensity on the reference block placed on the film may differ from that on the test specimen if SFD is not sufficiently large. It may cause an error in the corrosion evaluation using the film density comparison technique.
- In addition to the above, in general it was found out that ID defects in pipes that also have a deposit were difficult to gauge. The same is true for OD defects when the insulation has high radiation absorption.

6. CONCLUSIONS AND RECOMMENDATIONS

The CRP conclusions and recommendations are as follows:

- Tangential radiography and density measurement techniques are complementary methods. However for insulated pipes only tangential radiography is recommended, since the density measurement method requires complicated simulations.

- It is expected that the wall thinning due to uniform corrosion is irregular in the pipe's cross section, hence the density measurement method is not recommended, because it gives only the average wall thickness.

- For determination of the depth of pits and local corrosion areas, the density measurement method is recommended. The tangential radiography is not suitable because it is difficult to get a pit at a tangential position, thus requiring a large number of shots. This consumes more time. In the density measurement method, the use of low energy is advisable to get a high contrast. Using this method, the pit (local corrosion area) should lie on the film side during exposure to prevent an underestimation of its depth.

- The dimensions of a pipe wall or pit can be determined by scanning the radiograph with a scanning micro-densitometer. Other tools, such as optical devices or ruler may also be used to measure dimensions in the image. In the density measurement method the pit depth is determined from the density-thickness reference curve.

- In tangential radiography, the maximum penetrated thickness of pipe wall has to be considered for the energy selection of X rays. To prevent burn-off at the outside extremity of the pipe, filtration is necessary in order to cut the low energy components of the X ray beam. If available, the Ir-192 isotope is recommended instead of X rays to get a better definition in the tangential radiography technique.

- The problem of the burn-off at the OD extremity and poor definition at the ID extremity of the pipe wall can be improved by applying double film techniques, i.e. using two films of different speeds which are superimposed. This helps to identify the OD and ID extremities much better.

- Low speed films are recommended especially for the density measurement technique. For the tangential technique, the speed of the film is not very important. A lead-intensifying screen should be used in close contact with films. A lead plate should also be used behind the film to protect against backscattering.

- Accuracy of the density comparison method also depends on the conditions of the density measurement. Using a film density as high as possible within the measurability range is advisable for better resolution in thickness terms.

- Application of tangential radiography in the determination of deposit in pipes filled with fluids (operational pipes) is restricted because of the small density difference between deposits and the fluids. However, deposit thickness can be found by the density comparison method if a stepped block of the deposit material can be made and used.

CRP PARTICIPANTS' REPORTS

CORROSION AND DEPOSIT DETERMINATION IN PIPES BY RADIOGRAPHY

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Abstract

One of the most important parameters in a piping or pipeline to be monitored and measured is the wall thickness. Only radiographic method assures inspection without costly removal of insulation material during operation of the plant. An additional advantage is that these techniques can be even applied in high temperature environments. Radiographic evaluation of the deposits/scales in pipes (insulated or not) is also an effective NDT technique. In this project, 12 samples that were the subject of a Round Robin Test were inspected by the tangential technique. Results obtained by our laboratory for all pipes were discussed in a joint meeting. Evaluation was done considering the success rate in detection of corrosion as well as the minimum remaining wall thickness.

1. INTRODUCTION

The reliability and the safety of industrial equipment in the petroleum industry and power plants are substantially influenced by degradation processes such as corrosion, erosion, deposits and blocking of pipes, which might reduce production, cause leaks, fires or unpredictable and costly shutdowns due to repair and replacement.

The condition of critical components in these industries can be monitored by the proper use of NDT inspection methods even while the plant is in operation, thus making possible the planning of components replacements, repairs, deposit removal and shutdowns. Preventive and corrective maintenance averts the environment and the public from excessive risk of industrial disasters.

One of the most important parameters in a pipeline to be monitored and measured is the wall thickness. Only radiographic method assures inspection without costly removal of insulation material during operation of the plant. An additional advantage is that these techniques can be even applied in high temperature environments. Radiographic evaluation of the deposits/scales in pipes (insulated or not) is also an effective NDT technique.

2. THEORETICAL CONSIDERATIONS

Tangential radiography method principle

The tangential radiography method using X and gamma rays to determine tubes thickness is a very delicate method that requires a meticulous setting and optimization of parameters such as the time of exposure, the distance source-film, the gamma ray energy, etc.

The radioisotope sealed source Ir-192 with activity of 3700 GBq is applied normally in this method. The source is placed relatively far from the pipe tube in order to project the two walls of this tube onto the film. Because of finite dimensions of the radioactive source, a fuzzy effect (unsharpness or penumbra) appears on the film. To be able to decrease the effect of fuzzy, studies showed that the operator should use SFD superior to 8 times tube diameter.

3. EXPERIMENTAL SET UP

The tangential radiography was applied according to the known experimental set up. The NDT laboratory has prepared different specimens for network cooperation in the frame of round robin test.

Several tubes are cut up in 300 mm of length with 25, 50, 100 and 150 mm diameter. Internal and external grooves (longitudinal and transversal) are manufactured to permit simulation of corrosion. Other tubes have suffered a local attack by an acid to permit the obtaining of a local corrosion. All alternatives were taken account: straight or bent, reinforced tubes either insulated or not insulated.

Steel was taken as material of work. The second set of tubes has been appropriated from industrial installations containing a real corrosion such as erosion, deposits or pits. Exchange of samples was practiced in order to perform different tests in various conditions.

4. EXPERIMENTAL RESULTS

In this project 12 samples, that were the subject of the Round Robin Test, were inspected by the tangential radiography technique. The specimens tested in national NDT laboratory were:

- 1st tube with 200 mm diameter
- 2nd tube with 250 mm diameter
- 3rd tube with 300 mm diameter
- 4th tube with 400 mm diameter

These specimens were tested by the same tangential radiography method. Films of all these tests were sent to France for intercomparison. There was a good confirmation of results from both NDT laboratories. Results obtained by NDT national laboratory for all pipes were discussed in a joint meeting and are presented in the summary of results of the whole CRP.

In addition the following investigations were performed:

- Three tubes from France were inspected with a good precision of remaining measured thickness and detection of all defects. The sizing of defects was given with a maximum deviation of 2 mm;

- Three tubes from Syria were inspected with a good precision of remaining measured thickness. All fabricated defects tubes were detected and good sizing with a maximum deviation of 5 mm;

- Three tubes from Turkey were inspected with a good precision of remaining measured thickness. Some real pits, deposits and other defects have been detected with a maximum deviation measured of 1.5 mm;

- Two tubes from Algeria were inspected with a good precision of remaining measured thickness. All fabricated defects tubes were detected and good sizing;

- One tube from Tunisia was inspected containing a uniform corrosion.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, First RCM report on validation of protocols for corrosion and deposit determination in pipes by radiography, Çekmece Nuclear Research and Training Centre, Istanbul, 15–19 Sept.1997.

[2] BURKLE, W.S., Application of tangential radiography technique for evaluating pipe system erosion/corrosion, Mater.Eval. Vol. 47, Oct.1989.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Second RCM report on validation of protocols for corrosion and deposit determination in pipes by radiography, Syrian Atomic Energy Commission, Damascus, 17–20 May 1999.

VALIDATION OF PROTOCOLS FOR CORROSION AND DEPOSIT DETERMINATION IN PIPES BY RADIOGRAPHY

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Abstract

Chinese experts have been actively participated in the CRP project to improve radiographic methods and develop testing protocols. Besides it, some R & D works, such as gamma scanning digital system, ultrasonic pigs, real-time radioscopy and gamma computer tomography techniques are carried out. In this paper only the radiography, film image digital processing and testing procedure are reported. The tangential radiography and film processing techniques is a powerful and effective NDT method for pipe corrosion/erosion/deposit examination without remove insulator.

1. INTRODUCTION

Transportation of liquid and gas matters by using piping is most economical and efficient way. Up to now more then 20,000 km long pipeline and 300,000 km piping have been working in China. Due to chemical, electrochemical reactions or/and erosion pipe wall thinning, corrosion pits and cracks will be caused during service live time and the deposit formed by the accumulation of slugs and other precipitation will results in reduction of the efficient cross-section of pipe. So Non-destructive determination of corrosion/erosion and deposit in in-service pipe and pipeline is important in terms of their operation life, economic use and safety.

According to pipe operation practice the frequent accidents generally happen in the beginning and later period of operation. In China many pipes and pipelines have been operating since more then 20-30 years. So development of NDT method for monitoring corrosion and deposit in pipelines and piping systems without remove insulator is an urgent problem.

Chinese experts have been actively participated in the CRP to improve radiographic method and develop testing protocols. Beside it, some R & D works, such as gamma scanning digital system, ultrasonic pigs, real-time radioscopy and gamma computer tomography techniques were carried out. In this paper only the radiography, film image digital processing and testing procedure are reported.

The tangential radiography enables directly measuring pipe wall and deposit layer. Applying the tangential radiography the views of pipe cross-section and of tangential sections are projected onto the film or display plate.

When an irradiation beam of X/γ rays passes through a specimen to be tested, its intensity decreases due to the absorption processes in the material. The amount of lost radiation intensity depends on the quality of radiation, the material density and the transversal thickness. For monochromatic beam the transmitted beam intensity (I) can be calculated by the following equation:

$$I = I_0 B e^{-\mu\chi} \quad (1)$$

Where

- I_0- the incident beam intensity;
- μ - the linear absorption coefficient of the material,
- x- the transmitted thickness;
- B- the scattering factor.

When using tangential radiographic method the minimum transmitted pipe thickness is zero at the pipe tangential points. The maximum transmitted thickness is the pipe diameter. Because at the tangential points projection gives too dark image (burn-off) while at pipe center transmitted radiation produces too bright image, the selection of optimal tangential projection configuration providing adequate exposure on to the film is very important preliminary step.

Theoretical intensity versus pipe tube diameter (I-r) curves for different conditions are shown in Fig. 1. The inflection points of the curves reflect the boundaries between different layers. Distances between the inflection points correspond to the thickness of layers.

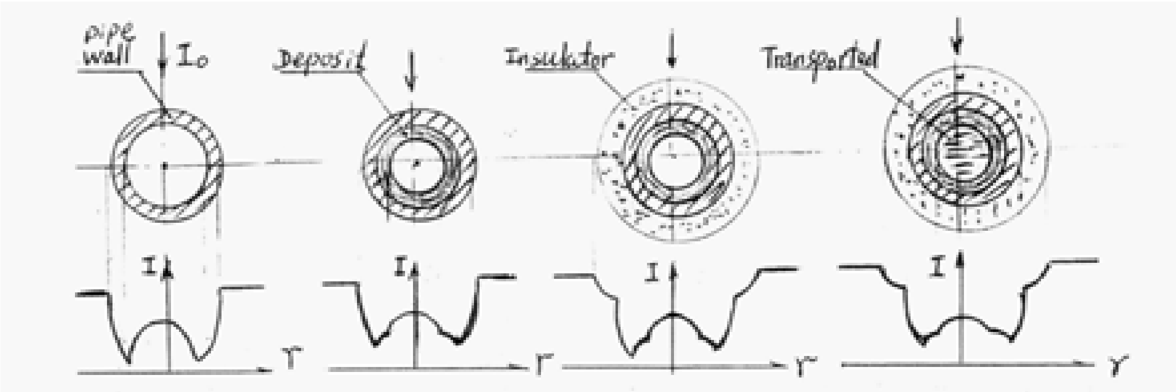


FIG. 1. Typical intensity curves of tangential radiography.

2. RADIOGRAPHY METHOD

The tangential radiography is a powerful and easy realizable NDT method for pipe corrosion and deposit evaluation. But some testing factors must be considered carefully.

During taking tangential radiography the transmitted thickness has a wide range and the maximum transmitted thickness is much more two times of pipe wall, so higher voltage X rays or higher energy gamma ray sources must be used. The general principles for select radiation source are the followings:

- The film optical density at the half of maximum thickness should be about 2–2,5;
- The soft energy radiation should be as lower as possible to limit the Compton scatter effect;
- With considering practical conditions the collimator and necessary safety shielding should be used

The Ir-192 gamma source was successfully applied to tangential radiography of pipe with 25–219 mm diameter. X rays have continued energy specter, so when using X ray units, some precautions such as filtering of soft rays, should be taken.

For piping test conditions a fix stand was mounted on the pipe. The source-film distance (SFD) was adjusted and the collimator, reference block and film cassette were arranged on the stand. Considering wide range of thickness and scattering effect the radiography film with wide latitude and thick Pb-screens were used.

3. FILM IMAGE DIGITAL PROCESSING TECHNIQUE

Radiography image processing technique has been widely used in medical and industrial radiography film interpretation. For more accurate and effective evaluation of corrosion and deposit the special technique of computer assistance film digitalization/image processing was developed. The film processing system consists of a radiography illuminator, a high resolution B/W camera and a computer with special software. The processing procedure for tangential radiography film was the following:

- Digitalization of the film by using camera and adjustable illuminator (all grayness ~20–240);
- Negative/positive image conversion and noise flitting for getting high quality pipe images by using contrast, density and edges enhance;
- Density distribution curves of the pipe cross section through the wall and deposit to be tested;
- Measuring the wall and deposit thickness by using the inflection points of curve;
- Measuring density-thickness reference curve by using the stepped wedge image and density curves through pit to be tested;
- Measuring the pit depth by using the reference density curve.

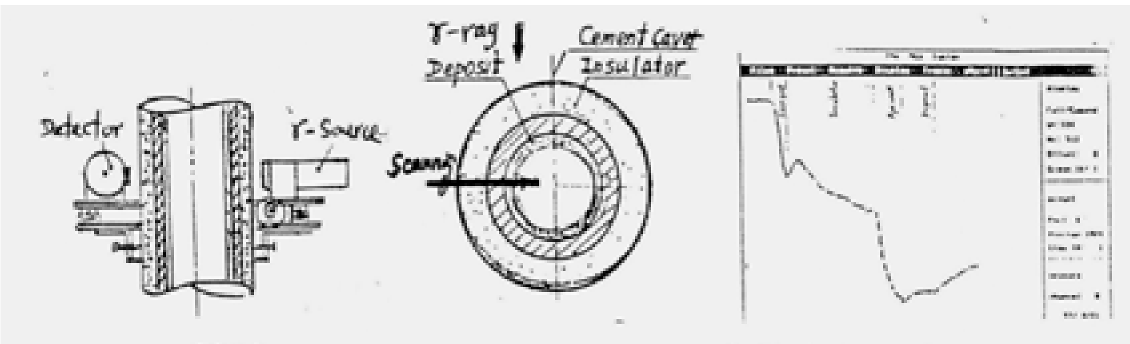
4. TESTING PROCEDURE AND PROTOCOLS

The testing procedure of corrosion and deposit inspection by radiography and draft national standard have been developed.

Gamma scanning digital technique

Gamma ray scanning digital system (GSDS) was developed in the national NDT laboratory as an additional technique to the tangential radiography.

The testing principle is same as in tangential radiography. The GSDS system consists of a low activity Cs-137 gamma source (1 GBq), a high sensitive detector, a pre-amplifier, a multi channel analyzer, a stepped processing scanner and a computer system. The system can finish real time test process and give visible curves to measure the wall thickness/deposit in short time. The curves are similar to density distribution curves obtained by film processing (Fig. 2). The advantage of the method is higher safety.



(a) GSDS system (b) typical record curve

FIG. 2. Gamma ray scanning digital technique.

Density profile across the pipe for radiographic images obtained for some typical specimen is given in figure 3.

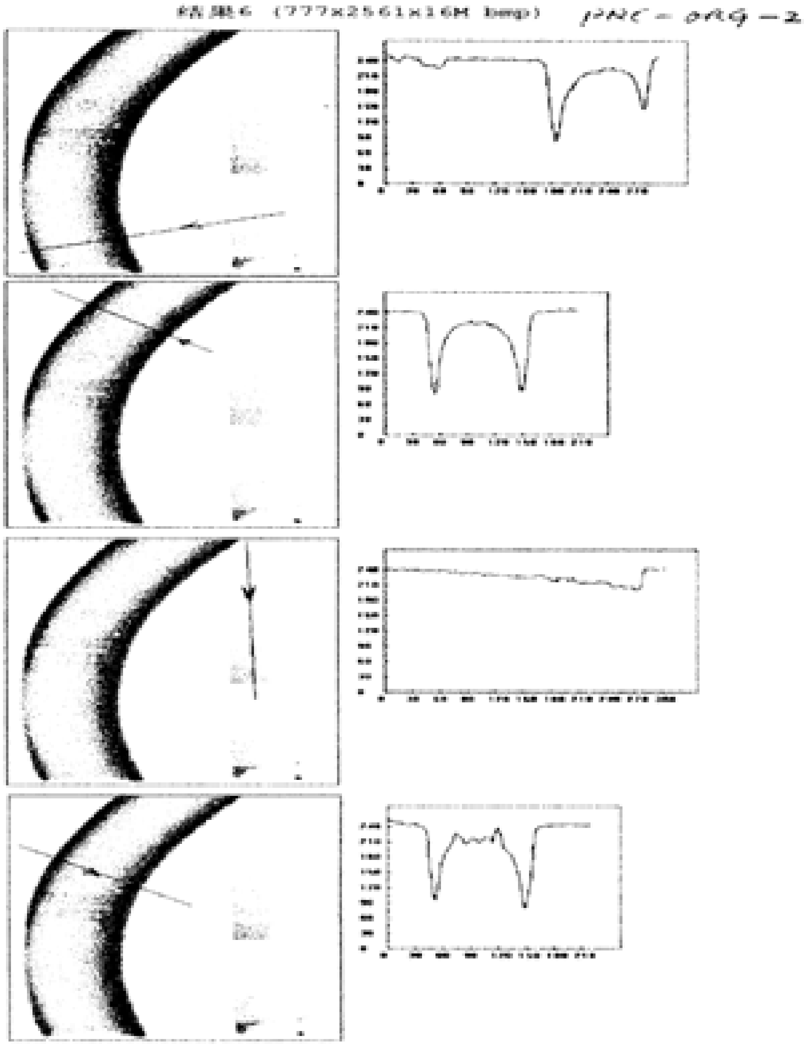


FIG. 3. Density traces across the radiographic images.

4. ROUND ROBIN TEST RESULTS

The round robin test (RRT) pieces fabricated by China, Rep. of Korea, India and Sri Lanka have been examined and evaluated by the radiography method and checked by gamma scan digital system according to established protocols. During the CRP period some original pipes supported by Shushing Chemistry Company and Laohe Oil field have been tested and destructive examined.

The radiographic testing results were compared with ultrasonic thickness gauge. For checking the testing technique and protocols one original pipe with corrosion and deposit similar has been tested destructively.

5. CONCLUSION

The tangential radiography and film processing techniques is a powerful and effective NDT method for pipe corrosion/erosion/deposit examination without remove insulator. In particular it helps the NDT laboratories in developing countries to improve their performance and provide accurate services to industry. The CRP project has developed, tested and validated material and protocols for applying the tangential radiography method in routine service to industry.

REFERENCES

[1] DOBROWOLSKI, M. "CORDEP-96" Personal report, 1997

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Report of 1st RCM of CORDEP-96 CRP, Istanbul, Rep.1997

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Report of 2nd RCM of CORDEP-96 CRP Damascus, May 1999

VALIDATION OF PROTOCOLS FOR CORROSION AND DEPOSIT DETERMINATION IN PIPES BY RADIOGRAPHY

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Abstract

The research work carried out at the Institute of Technology in Costa Rica consisted in developing radiographic protocols and instructions for identification and measurement of corrosion and deposits in operational pipes. The tangential radiographic method was applied to measure corrosion, deposits, pitting, and wall thickness remaining in insulated and uninsulated pipes. The protocols developed during the CRP facilitate the technological transfer from the university to the industrial sector.

1. INTRODUCTION

The principles of corrosion determination and monitoring by means of film based tangential radiography are well known worldwide. This technique is largely applied in petroleum and power sectors. Several thousand tests a year have been reported by NDT servicing companies. Successful and cost-effective radiographic determination of deposits, in those companies, has been reported too.

In spite of rather long tradition, there are no internationally recognized procedures and recommended practice for radiography techniques as applied for pipe corrosion and deposit measurement. Typical arrangements (one wall — one image, two walls — one or two images) as well as geometrical conditions, number of exposures, source/energy selection, and interpretation principles are not yet standard. Costly mistakes may occur applying radiography testing without any standard. Lack of reliable radiography testing (RT) procedures discourages sometimes the NDT centers in developing countries to propose services to potential customers from industry.

In Costa Rica, the NDT technology is in development. The working partnership with industry has been establishing. Some companies have their own small NDT laboratories for activities within the company. The Institute of Technology has a well-equipped NDT laboratory.

Evaluation of wall thickness by tangential radiography technique is applied in those cases in which it is needed a more detailed wall evaluation. It is recommended to use first a very fast technique for wall evaluation, such as film density. Utilization of the tangential radiography technique presents some problems in Costa Rica, because of the lack of appropriate tools for reading and interpreting results.

During the CRP period the NDT laboratories in Costa Rica have developed the following activities:

(a) Testing of specimens and preparation of results;

(b) Round robins test within Costa Rica, rotating the samples among the four listed laboratories;

(c) Training personnel in the technique of tangential radiography;

(d) Contacting industries interested in the application of this technique;

(e) Participation in the CRP meetings.

2. DETAILS OF TEST SPECIMENS

At the beginning, it was planned to use three specimens, one fabricated and two originals. But it was difficult to find proper original specimens. One of the original pipes had an outer diameter larger than 152.4 mm, and created problems for correcting its film image. The fabricated specimen resulted with induced imperfections that made it hard to evaluate. Moreover, the kind of induced imperfections were very rare to find in industries. Then it was replaced by another better fabricated.

The following are detailed specifications of the fabricated and original specimens investigated in the frame of the CRP:

Test classification and description for the fabricated specimen

Pipe classification
CR-FAB-135XF-1A2A3A-4-5-6E7A8B9D-10 (Code FAB-01)

Pipe description
This pipe had a diameter and thickness of 60 mm. It is frequently used in industries, particularly for transporting steam, water and other liquid components. Its wall thickness was of 3,2 mm, while the length was 260 mm, and its inner eccentric diameter of 43,7 mm. It is made of carbon steel galvanized, and welded at the length. It was created a deposit of ceramic materials simulating an incrusted in eccentric form.

Test classification and description for the original specimen

Test category and classification
ORG-135XF-1E2A3B4A5A6E7A8D9A10AB (Code ORG-1)

Pipe description
This original pipe was insulated. It was representative of the most usually utilized pipe in geothermal plants, petrochemistry industries and general industry. This test pipe presented the generalized corrosion both inner and outer; in some segments a level of penetration of around 1, 5 mm was created during the operation. A corrosion deposit of 1 mm thick was located between sectors 1–5 and 4–8 near central part.

Concerning welding, the pipe presented extra metal in the top of the weld of around 1 mm in the sector 1-5 and the inner of pipe the weld is undermined. It was observed extra metal at the top of the weld of 2,5 mm. Inside, it was also produced extra metal at the bottom of the weld in the same sector. In the sector 3–5 extra metal in the top of the weld of 6 mm was produced, while in the sector 4-8 the extra metal was of 4 mm. The thickness average is of 5, 5 mm.

The goal of the project was to evaluate by radiography these kinds of imperfections and to determine the degree of precision in this evaluation.

3. EXPERIMENTAL SET UP AND PROCEDURES USED INCLUDING THE TEST PARAMETERS

Several preliminary tests were performed to determine the right parameters for time, energy and film density using as reference those parameters indicated in the mentioned references. It was also fabricated other specimens different from those used in the round robin test aimed at evaluating dimensional variations in the application of the technique.

Additionally to this information, the companies participating in the round robin test have received a copy of the appropriate bibliographic references, some recommendations related to radiographic identification, radiographic definition, utilization of the standard block, geometric shape, and application of methods for image correction, utilization of IQI, parameter modification, and illustrations of the two basic arrangements for tangential and concentric radiographies. It was included also a technical report describing both film density and tangential techniques. Finally, a procedure was written and distributed to the participants in the mini round robin test (among NDT laboratories inside Costa Rica) including sheets and formats for reporting both radiographic arrangement and results.

Mini round robin test flow

A national mini round robin test was carried with participation of NDT national laboratories. The four national laboratories, i.e., institutions equipped with basic infrastructure for applying radiographic techniques, were the following:

- Institute of Technology of Costa Rica (ITCR)
- Instituto Costarricense de Electricidad (ICE),
- Refinadora Nacional de Petroleo (RECOPE) and COOPESA.

Proposed mini round robin test was organized according to the following flow:

Start ⇒ ITCR ⇒COOPESA ⇒RECOPE ⇒ ICE ⇒ results discussion ⇒ ITCR.

Test parameters

The following parameters and general recommendations were utilized by industries in test evaluations:

ORG-01

A. Test conditions:

X ray equipments

a. Source-film distance (SFD): 700 mm
b. Voltage: 160 kV
c. Ampere: 5 mA
d. Time of exposition: 1 min and 50 secs
e. Film: Kodak industrex AA-400, with a lead screen of 0,027 mm or equivalent

Gamma ray sources

f.	Source:	Gamma-ray, ^{192}Ir
g.	Activity:	4366 GBq (118 Ci)
h.	Source size:	Collimator 60°
i.	Exposition time:	50 secs.
j.	SFD:	700 mm
k.	Film:	Kodak industrex AA-400, with a lead screen of 0,027 mm

B. Radiographic arrangement:

a. Use both concentric and eccentric techniques.
b. Indicate clearly the sector under evaluation. Each specimen is divided into sectors to facilitate identification.

FAB-01.

A. Test conditions:

X Ray equipments

a. SFD: 700 mm
b. Voltage: 160 kV
c. Ampere: 5mA
d. Time: 2 min.
e. Film: Kodak industrex AA-400, with a lead screen of 0,027 mm or equivalent.

Gamma ray sources

- a) Source Gamma-ray, ^{192}Ir
- b) Activity 4366 GBq (118 Ci)
- c) Source size Collimator 60°
- d) Exposition time : 50 sec
- e) SFD 700 mm
- f) Film Kodak industrex AA-400, with a lead screen of 0,027 mm

B. Radiographic arrangement:
(The same as before).

4. RESULTS OBTAINED

Results obtained during three years of CRP period are presented in Table I.

TABLE I. MINI ROUND ROBIN TEST RESULTS

Specimen number	***Specimen details***	***Nature of defects***	***Tested by***	***Test parameters***	***Results***	***Remarks***
ORG-01	Dia: 60mm Th: 5,5mm Leng: 190 mm Straight Insulated	Generalized corrosion/ wall thickness remaining	ITCR	Source: X ray, 160 kV, 5mA Source size: 3mm Exp. Time: 1min, 50 sec. SFD: 700 mm Dev: 5 min, 20 °C, Manual Exp: 1	Wall Thick. 5,6 mm	It was detected severe corrosion attacks, both inner and outer. Weld defected
FAB-01	Dia: 60 mm Th: 3,1 mm Leng: 260 mm Straight Uninsulated	Deposits Max: 8,8 mm, Mid: 3,4 mm/ Wall thickness remaining	ITCR	Source: X ray, 160 kV, 5mA Source size: 3mm Exp. Time: 2 min. SFD: 700 mm Dev: 5 min, 20 °C, Manual Exp: 1	Deposits: from 8 mm to 8.5mm Wall Thick. 3,25 mm	As indicated dimensions of deposits depend of the sectors under evaluation

Specimen number	*Specimen details*	*Nature of defects*	*Tested by*	*Test parameters*	*Results*	*Remarks*
FAB-01	Dia: 60 mm Th: 3,1 mm Leng: 260 mm Straight Uninsulated	Deposits Max: 8,8 mm, Mid: 3,4 mm / Wall thickness remaining	JAMSA	Source: Gamma-ray, ^{192}Ir Activity: 4366 GBq Source size: Collimator 60° Exp. Time: 50 sec. SFD: 700 mm Dev: 5 min, 20 °C, Manual Exp: 2 @ 90°	Deposit: Maximun 8,5 mm; Middle 3,7 mm Minimun 1,1 mm Wall Thick. 3,1 mm	
ORG-01	Dia: 60mm Th: 5,5mm Leng: 190 mm Straight Insulated	Generalized corrosion/ wall thickness remaining	JAMSA	Source: Gamma-ray, ^{192}Ir Activity: 4366 GBq Source size: Collimator 60° Exp. Time: 50 sec. SFD: 700 mm Dev: 5 min, 20 °C, Manual Exp: 1	Wall thick. 5,58 mm	It was detected meaningful corrosion attacks, both inner and outer. Weld defected

Specimen number	*Specimen details*	*Nature of defects*	*Tested by*	*Test parameters*	*Results*	*Remarks*
FAB-01	Dia: 60 mm Th: 3,1 mm Leng: 260 mm Straight Uninsulated	Deposits Max: 8,8 mm, Mid: 3,4 mm / Wall thickness remaining	ICE	Source: X ray, 160 kV, 5 mA Source size: 3mm Exp. Time: 5 min. SFD: 700 mm Dev: 5 min, 20 °C, Manual Exp: 2@ 90°	Deposit: Max. 10.9 mm Middle1: 8.9 Middle2: 8.9 Lower: 3.9 Wall thick. 3.3 mm	In two films deposits were clearly appreciated
ORG-01	Dia: 60mm Th: 5,5mm Leng: 190 mm Straight Insulated	Generalized corrosion/ wall thickness remaining	ICE	Source: X ray, 160 kV, 5mA Source size: 3mm Exp. Time: 4 min, 30 secs. SFD: 700 mm Dev: 5 min, 20 °C, Manual Exp: 1	Wall Thick. not detected	Corrosion was not detected

Specimen number	*Specimen details*	*Nature of defects*	*Tested by*	*Test parameters*	*Results*	*Remarks*
FAB-01	Dia: 60 mm Th: 3,1 mm Leng: 260 mm Straight Uninsulated	Deposits Max: 8,8 mm, Mid: 3,4 mm / Wall thickness remaining	COOPESA	Source: X ray, 160 kV, 5mA Source size: 2,7mm Exp. Time: 5 min. SFD: 700 mm Dev: 5 min, 20 °C, Manual Exp: 2 @ 90°	Deposit: Max. 7.0 mm Min: Wall thick. 4.1mm	Test specimens were passed to COOPESA again, to complement and improve results
ORG-01	Dia: 60mm Th: 5,5mm Leng: 190 mm Straight Insulated	Generalized corrosion/ wall thickness remaining	COOPESA	Source: X ray, 160 kV, 5mA Source size: 2,7mm Exp. Time: 4 min, 50 secs. SFD: 700 mm Dev: 5 min, 20 °C, Manual Exp: 1	Wall thick. 5,7 mm	Corrosion: inner and outer Weld: lack of penetration

5. CONCLUSIONS AND RECOMMENDATIONS

1) When formula applied for estimating remained wall thickness, in some cases with high corrosion rate, the tangential radiography results give a slightly higher value than real thickness (measured by other techniques). The accuracy is smaller when real wall thickness is close to critic wall thickness.

2) In some cases, when using X ray equipments and density techniques for evaluating wall thickness in pipes with deposits, the transition region between metal and deposits were not clearly sharpened. Tangential radiography gives better accuracy that density technique in these cases. Double wall radiography (density technique) and tangential radiography are complementary to each other.

4) It was found out that to clearly sharp incrustations from metal, the optimal film density should range from 2.5 to 3.0.

5) The results obtained deviated from real wall thickness in a range of 3 – 8 %. This accuracy is acceptable.

Through interactions with industry, the following comments are with particular interest:

1) The tangential radiography method requires preliminary information and optimal procedures for efficient applications in situ. Industry wants to know the feasibility of this method in plant operation conditions.

2) It is necessary to have graphical information on classification and identification of defects due to corrosion, deposits and other typical defects in pipelines.

3) Industry wants information on economical aspect of the method that is not yet available. According to end users' opinion the tangential radiography method for determination of corrosion and deposit in pipes works well in specific cases but for massive and on-line testing of whole pipeline the cost-benefit aspect has to be investigated further.

REFERENCES

[1] BURKLE, W.S. (1989) "Application of the Tangential Radiographic Technique for Evaluating Pipe System Erosion/Corrosion" en: Materials Evaluation., Vol, 47, pp 1184–1188.

[2] EKINCI, S. (SFE) Remaining Wall Thickness measurements in Corroded water pipelines by radiographic techniques. Internal Report. Turkish Atomic Energy Authority.

[3] FENGGI, HE (1999) "Progress Report on Development of Corrosion/Erosion and Deposit Radiographic Testing". IAEA (1999).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Report of the second Research Coordination Meeting of the Co-ordinate Research Programme on Validation of Protocols for Corrosion and Deposit Evaluation by Radiography. Syria, Damascus, 1999.

[5] KROLICKI, R.P. (1977) "Internal Corrosion Examination and Wall Thickness Measurement of Pipe by Radiographic Method". Materials Evaluation, February 1977.

[6] LEE AND KIM (1999) "Determination of Pipe Thickness using Tangential Radiography and Film Density-Thickness Correlation". Progress Report, IAEA (1999).

[7] MUÑOZ J. AND VARGAS C. (2000) "Las Técnicas de Radiográfica Tangencial y Densidad de Película". Revista Mantenimiento. San José, Costa Rica.

COORDINATED RESEARCH PROGRAMME ON VALIDATION OF PROTOCOLS FOR CORROSION AND DEPOSIT DETERMINATION IN PIPES BY RADIOGRAPHY

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Abstract

The CRP aimed at developing radiographic protocols and instructions for identification and measurement of the corrosion attack and deposits in pipes (across insulation) in industrial installations during operation (on-line and in maintenance). The CRP addressed the needs of end-users in terms of developing reliable and appropriate NDT measurement protocols which refers to general requirements of international standards, (e.g. ISO 5579 – RT basic rules, ISO 1106 / 3 – RT circumferential weld in pipes, etc) with full implementations of recognized quality assurance methodologies. Radiographic evaluation of deposits in correlation with deposit geometry (flat, concentric, eccentric) and thickness was carried out.

1. INTRODUCTION

The CRP addressed the problem of testing and validating the radiography method for measuring corrosion and deposit in small diameter pipes. The CRP goal was also to demonstrate that operating method and measurement procedures defined by the NDT laboratories produce accurate and reliable results with a sufficient repeatability.

Details of test specimens were:

- FR1: Original piece of pipe, diameter 60 mm, length 320 mm, thickness 4 mm, natural defects inside such as general erosion and 1 corrosion hole.
- FR2: Original piece of pipe, diameter 115 mm, length 315 mm, thickness 6 mm, natural defects inside such as general erosion, 2 corrosion holes, 1 erosion zone (eccentric catch) and 2 artificial defects added such as 2 internal grooves.
- FR3: Original piece of pipe, diameter 168 mm, length 325 mm, thickness 8 mm, natural defects inside such as 2 corrosion holes and artificial defects added such as 2 internal grooves.

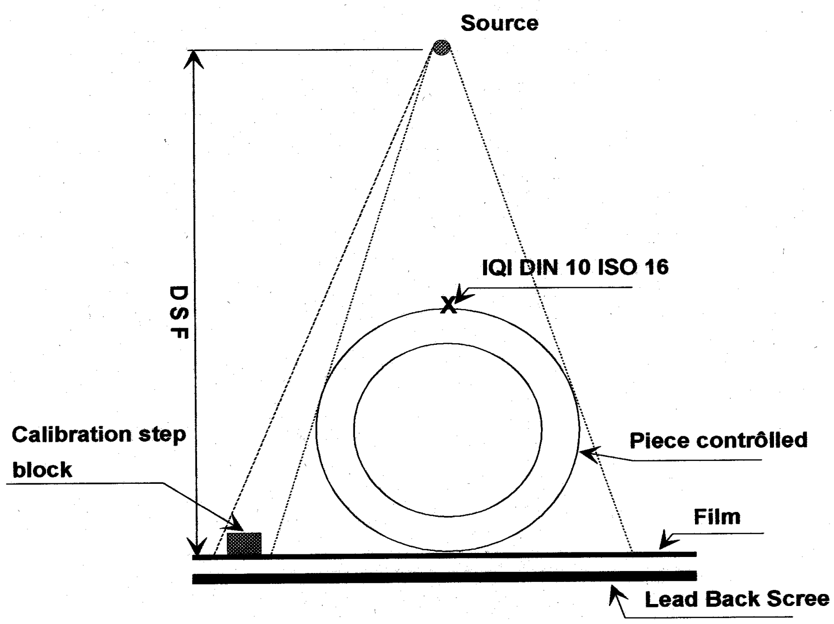
2. EXPERIMENTAL DESIGN

Exposures in the axial direction of pipe were performed to roughly determine whether defects are present or not (sketch 1).

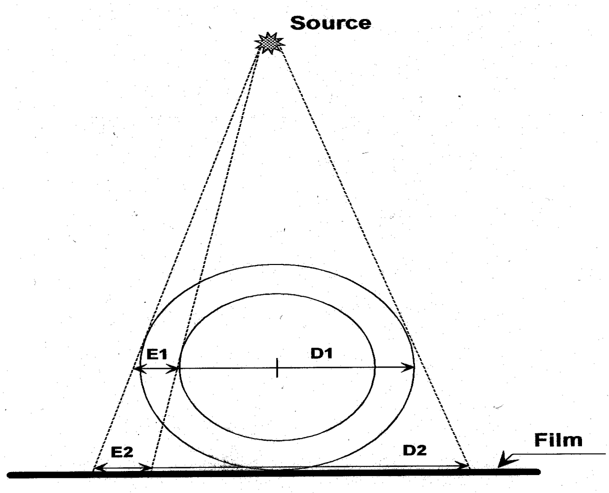
Thickness loss measurement was conducted as well. In case of insulation, one exposure is not sufficient and shoots here and there of a generatrice line have to be made under various incidences from the line (30° or 45°) (sketch 2).

After localization of defect or suspected area, additional exposures could be made in order to characterize with accuracy dimensions of defects or remaining thickness (sketch 3).

SKETCH N° 1

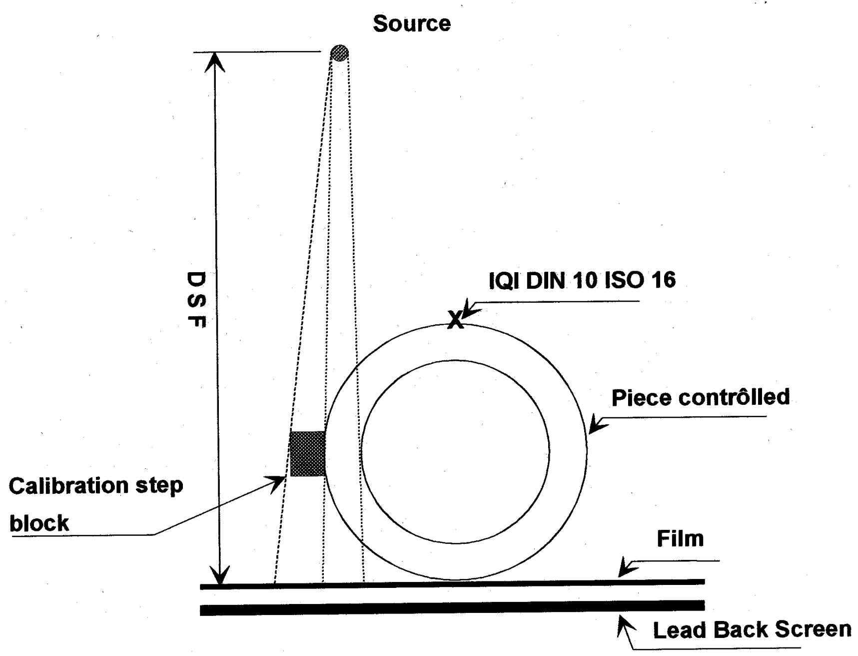


SKETCH N°2



1°) DETERMINE THE PROJECTED RATIO D1 / D2 = K
FOR A GOOD FILM QUALITY 0,8 < K < 1
2°) MEASURE D2 ON FILM
3°) CALCULATE RATIO K
4°) MESURE E2 ON FILM
5°) E1 = E2 x K
6°) % loss = E1 / E nominal X 100

SKETCH N° 3



3. EXPERIMENTAL SET UP AND PROCEDURES USED INCLUDING THE TEST PARAMETERS

The experimental set up consisted of:

- Gamma ray unit used: Ir 192, with activity 2220 GBq and 2590 GBq (60 and 70 Ci).
- Type of film used: Agfa D7 (single film) 30X40 and Vacupac D4 (single film) 30X40 and 10X40 (commonly used by petroleum and piping industries)
- Film density: around 3.
- Screens and filters used: in accordance with ISO 5579.
- Development used: Automatic machine Type AGFA NDT-M. Temperature: between 26°C and 28° (commonly used by petroleum and piping industries)
- Image quality indicator (IQI) used: DIN 10ISO16 placed on the film
- Calibration steps block (3 minimum steps) placed close to the piece.

4. CONCLUSIONS AND RECOMMENDATIONS

Comparison between film interpretation and destructive tests results show a difference up to 3 mm regarding sizing defect (this is consequence of incidental source position) and a difference up to 1 mm regarding sizing of general corrosion or erosion areas.

Minimum thickness of corrosion/erosion loss we can measure is 1 mm. Operating conditions and equipment used cannot permit to measure less than 1 mm.

Above 1 mm, we have a manually reading error of 0, 5 mm.

To obtain a good exploitable film interpretation, a time exposure with a minimum of 1 min. must be applied.

To be certain not to have any backscattered radiation which can mask defects, we proposed to place a lead sheet of 1.5–2 mm thickness behind the back lead screen. This additional filter has provided good quality pictures.

Exposures under insulated pipe are not easy to realize. Two or three shoots are necessary (instead of one when no insulation exists).

Usually, a little liquid is remaining inside pipes during shutdown and in-maintenance operations. To set free of that and avoid interpretation problems, an UT measurement is necessary before RT campaign.

Corrosion is consequence of chemical action. Erosion is a mechanical one’s. Sorts of corrosion / erosion may be different regarding transported fluids, liquids or gas. This could have an influence on detectable conditions depending sensitivity of radiograms used

A data bank has to be created of films depicting erosion-corrosion phenomena to facilitate selection of operating conditions and acceptance level of indications.

REFERENCE

[1] ISO 5579, Non-destructive testing — Radiographic examination of metallic materials by X and gamma rays — Basic rules.

[2] EN 444: Non-destructive testing: General principles for the radiographic examination of metallic materials using X and gamma rays.

[3] EN 462.1 Non-destructive testing: Image quality of radiographs part 1: Concepts, image quality indicators (wire type), determination of image quality value.

[4] EN 462.2 Part 2 for step/hole type.

[5] EN 584.1 Non-destructive testing: Industrial radiographic film part 1: Classification of film systems for industrial radiography.

VALIDATION OF PROTOCOLS FOR CORROSION AND DEPOSIT EVALUATION IN PIPES BY RADIOGRAPHY

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Abstract

Four pipe samples were prepared by India for the round robin test, two of them with natural defects and two artificial. A method to determine location of the minimum wall thickness in just two exposures is described, which can be used by all the participants. The third exposure taken tangentially can be used for assessment of residual wall. The report also outlines the digital methods of wall thickness measurement viz. by profilometry and by digital subtraction. Image plates using BaFBr phosphor were also explored for the use in wall thickness determination. Finally the results obtained by this laboratory on the pipes of other countries are tabulated.

1. INTRODUCTION

Importance of radiography technique (RT) in determination of wall thickness for insulated pipes is well recognized. Such requirement exists in industries like chemical, petrochemical and thermal power stations where pipes can corrode at inner or outer diameter below the insulation. Very often it may be necessary not only to know the minimum wall thickness remaining but also the location of such corrosion if remedial action is to be taken. As per the schedule of round robin test for Asian region, India received pipe samples from China, Rep. of Korea, Malaysia and Sri Lanka Most of these were packed in insulation or sealed to conceal the nature of defects, either natural or artificial.

2. THEORY

Estimation of wall thickness or deposit thickness can be done in any one of the two modes of radiography:

- The normal density method of double wall double image (DWDI);
- The tangential radiography.

DWDI technique is usable for pipes without insulation or where the radiation absorption of the insulation is much less than the absorption by the pipe material. Normally a stepped block is placed alongside the pipe while radiography is done. Comparison of density of the low wall area with that at various steps will indicate the total material thickness at the defect location. If T_{eq} is the thickness of the comparable step on the block, then subtracting the single wall thickness (WT) from T_{eq} will give remaining wall thickness of one side of the pipe. This is because T_{eq} represents double wall thickness.

$$W_{res} = T_{eq} - W.T.$$

Tangential RT

In tangential radiography the largest material thickness traversed by the radiation beam is along the tangent to the inner diameter (ID) (Fig. 1).

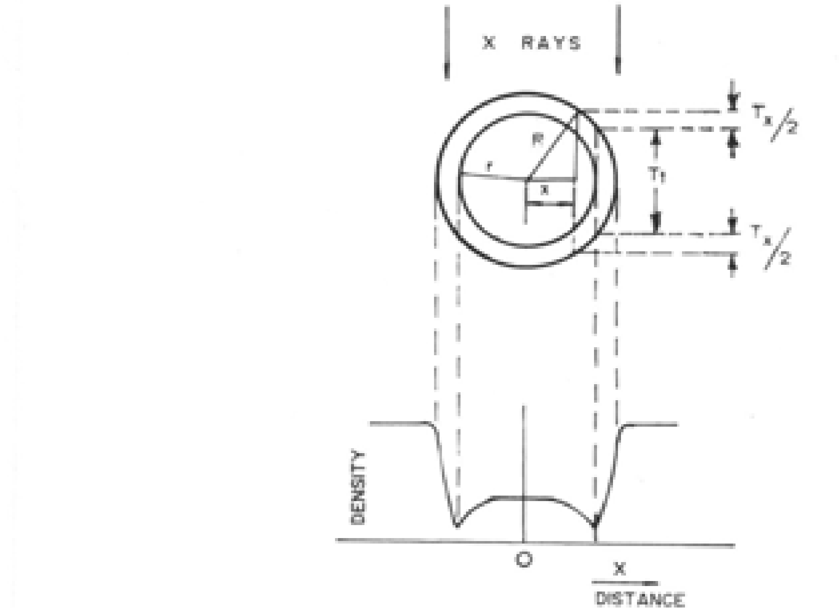


FIG. 1. Density trace across a pipe in tangential radiography method.

Thickness at a distance X is

- $T_X = 2(\sqrt{R^2-X^2} - \sqrt{r^2-X^2})$, for $|X| < r$
- $Tx = 2\sqrt{R^2-X^2}$, for $|X| > r$

At the location of ID tangent (i.e. at X = r) this reduces to

$$T_{tangent} = 2(\sqrt{R^2-r^2}) = (OD^2 - ID^2)^{1/2}$$

Assuming linearity between density and radiation intensity, the density profile will be

$$D = D_o\, B \exp [- \mu T_x]$$

B is a constant containing scattering and development effects.

The profile plot for thickness traversed (Fig. 1) shows that while approaching from the centre of the pipe to outside diameter (OD), the thickness reaches a maximum value abruptly at the ID tangent location. This facilitates the unambiguous marking of this location on the film.

There is however another area of concern. Very often the corrosion is not uniform but local, at a spot. To assess the residual wall thickness at this spot, the spot should be brought to the tangent location. But the main source of difficulty in determining the location is that each radiograph indicates two probable locations on the pipe along the direction of radiation beam. This is shown in the Figure 2. This fact can be made use of in finding the location. Let the pipe periphery be divided into twelve equal segments and identified them as 1 to 12 o'clock, located at 30^o to each other. The first radiograph is taken with the source above 12 o'clock position and the film is in contact with the pipe. Next the distance (x) of the defect from the right side edge of the radiograph is measured (Fig. 2).

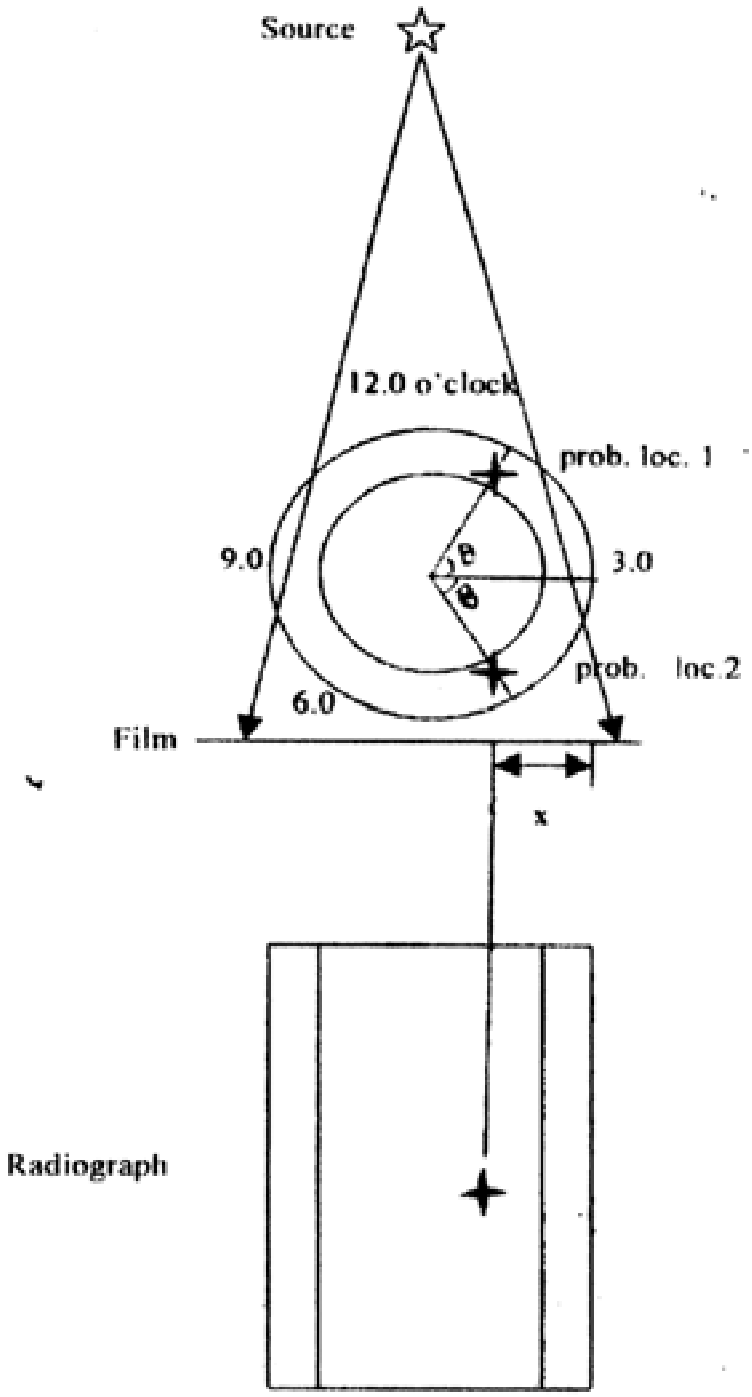


FIG. 2. Two possible locations for a defect in DWDI shot

If pipe diameter is D, then $\cos\theta = (D-2x) / D$, or

$$\theta = \cos^{-1}((D-2x)/D).$$

Therefore, the defect location in units of hours (o'clock) is

$$h = \theta/30 = \{\cos^{-1}((D-2x)/D)]\}/30 \text{ (}\theta\text{ is in degree)}$$

$$\text{or, } h = (6\theta)/\pi = [6\{\cos^{-1}((D-2x)/D)\}]/\pi \ (\theta \text{ is in radians})$$

The position of the right edge is 3 o'clock when RT is done from 12 o'clock. Hence the likely locations of the defect are

$$H1 = 3 + h \text{ o'clock}$$

$$H2 = 3 - h \text{ o'clock}$$

A second radiograph is taken from a location 120^o apart from the first location i.e. either 4 o'clock or 8 o'clock. Repeating the above arguments, the two optional locations for 8 o'clock source location will be

$$H3 = 11 + h \text{ o'clock}$$

$$H4 = 11 - h \text{ o'clock}$$

As the defect is one and the same for both the radiographs, there is a common source location for two radiographs, i.e. H1 or H2 will be equal to H3 or H4. Whichever location is there in both radiograph, is the actual location of the defect. If one is looking for the measurement of the wall thickness, then a third radiograph is taken in tangential mode by bringing the defect on the edge.

Computer program

The algorithm used here has one advantage over other algorithms, in the case where X> pipe radius (D/2) or D< 2x. In this case the defect is on the left half of the pipe diameter. It yields negative value for D-2x/D. The angle is then between $\pi/2$ and π. This cannot be found easily from the cosine tables, but a calculator or computer gives correct θ value even for a negative value of the (D-2x)/D. Considering this advantage of the selected algorithm, a simple interactive computer program was prepared in C-language to find the defect location. Flow chart for the program is given in Fig.3. It works as follows:

- As the start of the execution of the program, evaluator has to feed diameter of pipe (D), distance of indication from the edge on first radiograph (x1) and source location (o'clock1).
- The program will execute necessary computation and show the two probable locations on pipe if x1 # 0.
- To confirm the exact location of defect, the program will ask the evaluator to consider the second radiograph.
- The evaluator has to feed the lateral distance of indication on second radiograph (x2) and new source location (o'clock2).
- The program will display two more probable locations based on the second radiograph for which x2 # 0.
- Since defect is present at a definite location, there is a common location for first and second radiograph.
- At the final stage of execution, the program will compare all four probable locations from the first and second radiographs and will display the exact location on pipe.

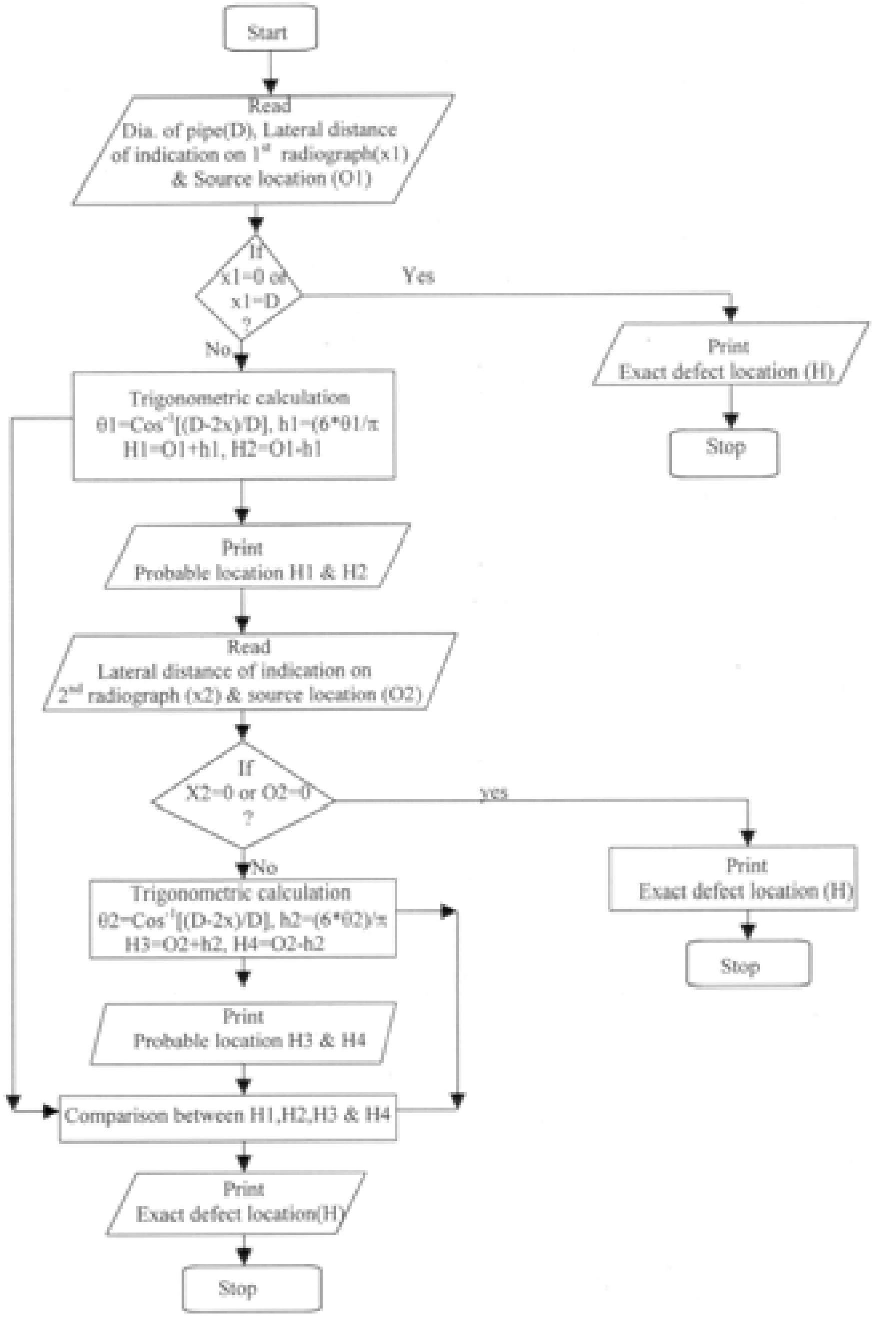


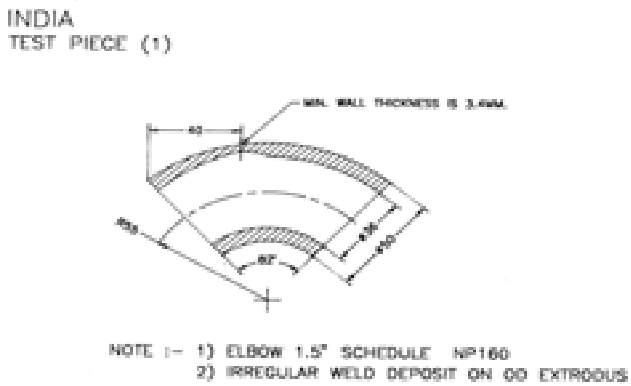
FIG. 3. Flow chart for the computer programme for location determination.

3. INDIAN SAMPLES

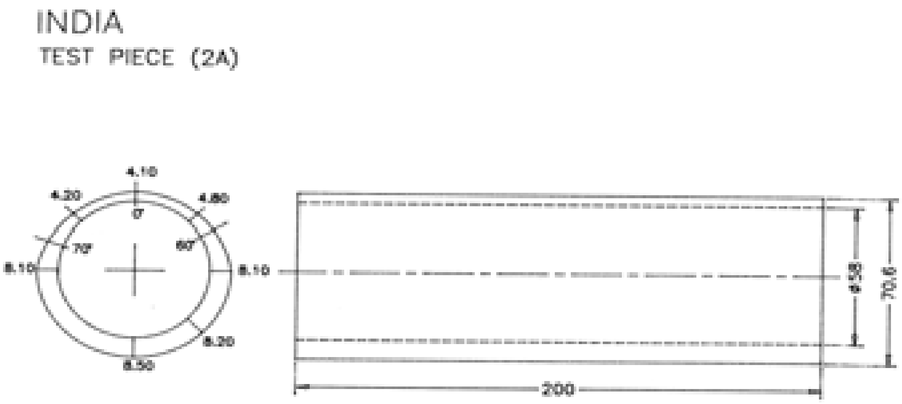
As a part of Round Robin Test (RRT) India also was to prepare defective samples. Four pipe samples were prepared in different diameter and thickness combination. Two of them were the real life samples obtained from a thermal power plant. One of them has a uniformly reduced wall thickness on OD, in half periphery, due to impingement of steam at that location. The details of nature and dimensions of the defects in all pipes are given in Table I. Their sketches are shown in Figures 4 (a, b, c, d). These specimens were encapsulated in aluminium case to conceal the defects. They were radiographed at our laboratory before sending for RRT.

TABLE I. PIPE SAMPLES FROM INDIA FOR ROUND ROBIN TEST (RRT)

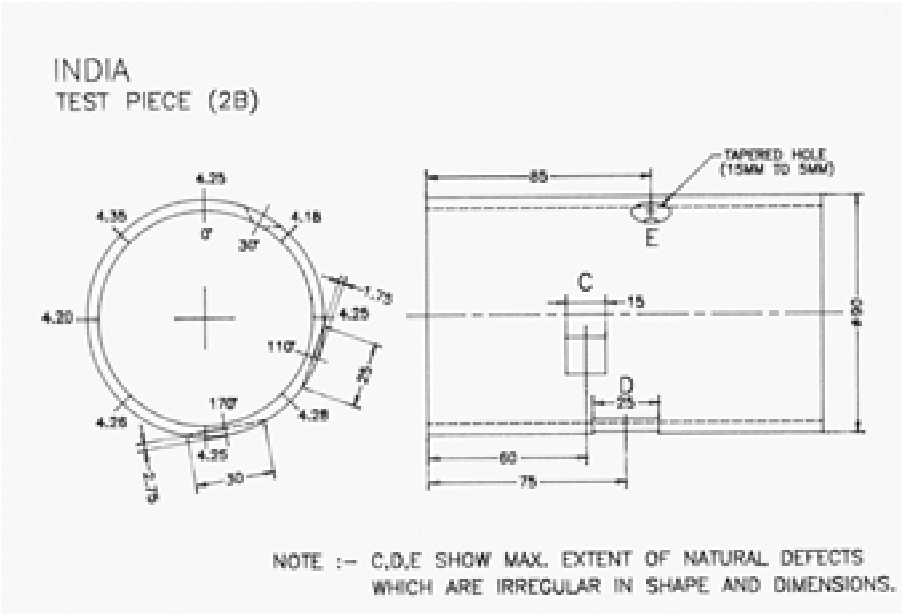
Sl no.	Identification	Type	OD	Nominal wall thick NT(mm)	Length L(mm)	Nature of defect	Dimensions of defect (mm)
1	IND-Fab.1	Elbow	50	7	-	Ground patch	40 long 3.5 deep
2	IND-ORG-2 A	Pipe	74	8	200	Erosion – corrosion	Full length Half periphery Min wall 4.1
3	IND-ORG-2B	Pipe	90	5 + 2mm bitumen for some length	200	Local corrosion areas	15x25x1.75 deep30x25x2.75 Tapered Hole 5 to 15 diameter
4	IND-FAB-3	PIPE	168	6	200	Milled notches	19x12x0.5 deep 19x27x1 deep 25x33x1.5 deep 37x30x2 deep



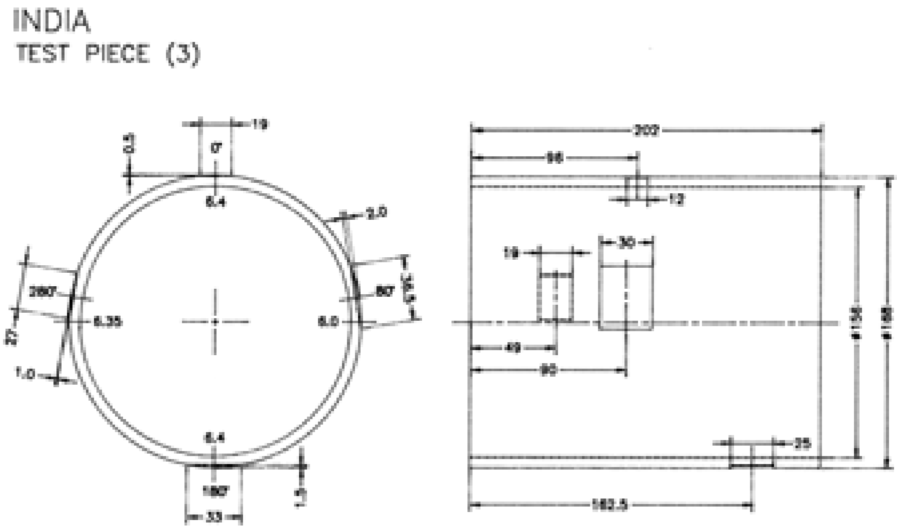
a). Sketch for pipe sample IND-FAB-1.



b). Sketch for pipe sample IND-ORG-2A.



c). Sketch for pipe sample IND-ORG-2B.



d) Sketch for pipe sample IND-FAB-3.

FIG. 4. Sketches for different pipe samples.

4. EXPERIMENTAL PROCEDURE

The experimental procedure has two aspects - taking radiograph and evaluating the radiograph. Radiographs were taken on X ray films. Some samples were also directly digitally recorded on an imaging plate phosphor. In the case of present CRP, the film evaluation is also equally important. It was done manually as well as by digital route, aided by computer.

Energy selection

General procedure for obtaining radiographs was as per article 2 of ASME Code, Section V. But the aspect of energy selection needs a special mention. In case of DWDI type of exposure (with the stepped wedge on a side), energy was as recommended by the X ray exposure chart. But in case of the tangential option, energy was based on thickness traversed Tt. Though one could prefer to take effective thickness as T/2 to avoid edge burning, it is not the best choice. The reason of using higher energy (corresponding to Tt rather than Tt/2) is that it delineates the ID profile more sharply. Lower energy produces higher contrast; that varies the optical density gradually around the ID tangent. What is required, on the contrary is that the density is nearly constant inside the ID boundaries and abruptly goes down at ID tangent. Hence high contrast, which is a virtue in flaw detection or in DWDI radiography is not so in tangential radiography. That is the reason we suggest Ir-192 source for all such combinations of OD and wall thickness where Tt is about 25.4 mm. In order to reduce the edge burning on the outer diameter, the exposure time should be reduced, but not the energy.

Exposure Sequence

As described in the Theory section, only 2 radiographs were adequate to locate the spot of minimum wall and one more in tangential mode to measure the wall. Following steps were followed:

- The pipe was marked with 12 equal segments called 1 to 12 o'clock;
- The first exposure was taken with radiation source at 12 o'clock location;
- The other exposure at 120^{o} apart, either 4 o'clock or 8 o'clock location.

After development, the film was interpreted holding it in such a way that the pipe is seen vertical and liquid flow is from bottom of the film to the top. This will bring the 3 o'clock position on the observer's right side edge and 9 o'clock on left edge. Now follow the following steps.

Measure the distance of the defect indication from the OD profile on the right edge. Call it X.

Calculate angle θ for the likely locations of wall thinning/defect.

$$\theta = \cos^{-1} [D-2x/D]$$

Convert this angle into o'clock location by formula:

$$\text{Hour } h = \theta \text{ (in degrees)}/ 30 \text{ or } 6\theta \text{ (in radians)} / \pi$$

This gives two likely locations as

$$3 \text{ o'clock} + h = H1 \text{ o'clock}$$

$$\text{or, } 3 \text{ o'clock} - h = H2 \text{ o'clock}$$

If H1 and H2 are between 2 o'clock to 4 o'clock (i.e. if $x < 0.067$ D), then step B can be avoided. One can directly take tangential exposures at 10 - 15^{o} to A location to determine the wall thickness.

Procedure is repeated with the other film (8 o'clock), which yielded H3 and H4. They were compared with H1 & H2. One of them was equal to H1 or H2. That was the location of the minimum wall spot.

The third exposure was taken with that location at tangential position. For further evaluation of wall, this last film was used.

5. EVALUATION OF IMAGES

Radiographs obtained by the foregoing procedures were evaluated for wall thickness measurement by two routes - manual and computer aided methods.

In manual method an optical comparator (graduated magnifying lens) was used for measuring wall thickness for tangential radiographs. Minimum graduation of scale was 0.1 mm and hence overall accuracy can be considered to be about 0.5 mm. For the films taken in DWDI mode, wall thickness was assessed by comparing optical density on the spot of reduced wall with the step wedge. As the wedge had steps in 1 mm, accuracy here was about 1 mm. Fig.5 shows radiograph of pipe Mal-org-3 with a step wedge. The pipe diameter is 179 mm and nominal wall is 7.6 mm. T_t is therefore 73 mm. Though this is on the border of capability of ^{192}Ir source, yet it was used. In addition DWDI technique was chosen. The step wedges of 12 to 18 mm (1 mm steps) and 3 to 25 mm were placed besides. The density on the defect location was nominally darker than that on 10 mm step.

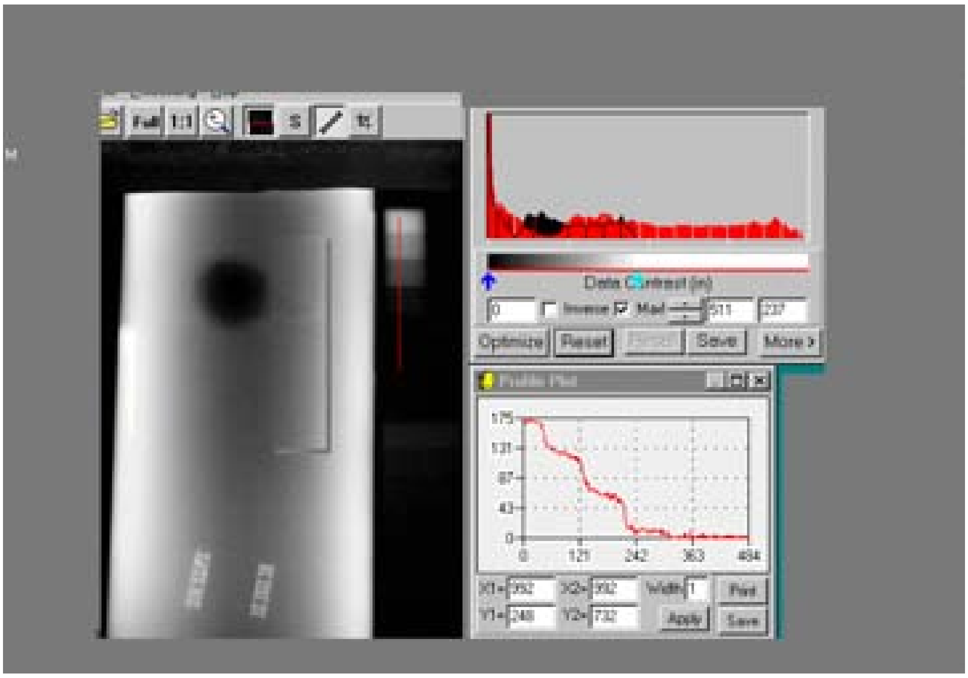


FIG. 5. Comparison of grey levels on step wedge and the defect indication (Pipe MAL-FAB-3). Top window is density histogram and bottom window shows density profile over step-wedge.

Thickness at the defect was evaluated of (10-7.6) = 2.4 mm or lesser. The tangential film showed about 1.5 mm as remaining wall. It was observed that the thickness of scale on ID side could be detected but its measurement was less accurate than that for wall reduction. Such pipes were more suitable for DWDI route.

Computer aided detection and evaluation

In situations where large number of identical radiographs is to be evaluated, manual assessment can be replaced by methods based on computers. This need can occur if the processing plant has pipelines in certain fixed diameters for long lengths.

For such semi-automated approach, first the film needs to be digitized. It can be done in three different ways:

- On scanner;
- Using a camera and a Frame Grabber Card;
- Using a digital camera.

Scanner is a standard attachment to a PC; but the scanner needed in film digitization has a special attachment to illuminate the films. We used a flat bed scanner with a resolution of 1600 dpi.

Camera based methods is used as well. Here the film is placed on a light source (illuminator) and in front of the camera with an appropriate lens. If the camera is an ordinary analogue camera, its output is given to a frame grabber card installed in a PC. It digitizes the picture. We used a low light level camera with a macrolens for the purpose.

On the other hand if the camera is a digital camera it creates picture in the magnetic memory of a special card on board. This card can transfer data to the PC memory directly or through a card-reader device. Camera used in our lab was DC 290 model of Kodak with 1500 x 2000 pixel format. Fig. 5 shown earlier was obtained through this route for pipe no. MAL-Fab-3.

Wall thickness assessment

Once the image of a corroded pipe is stored in a computer or a digital form, it can be manipulated to obtain wall thickness at the most vulnerable location. If required, image contrast and brightness also can be changed for this purpose so that the boundaries are more defined. Two different approaches were chosen to make wall assessment and demonstrate the feasibility, viz. (a) by digital subtraction and (b) by profilometry.

(a) Digital Subtraction

In this method, image of the pipe under inspection is compared with the image of a healthy pipe. The comparison is done by the computer in the digital field. Features like defect or low wall thickness will stand out in the subtracted picture. Figure 6 shows this technique applied on pipe sample India-Fab-3. The notch at tangent gets highlighted in the image. Figure 7 shows Mal-Fab-3 pipe with a defect (a ground patch). Digitally subtracting wall shows the wall profile and the defect (Fig.8). As the method helps in quick identification of zone of interest, it is useful when large number of films is to evaluate.

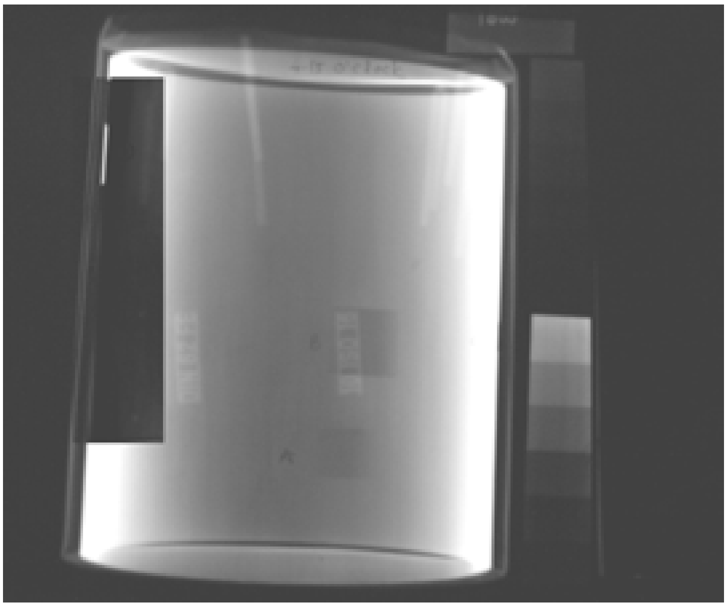


FIG. 6. Digital subtraction for an OD notch at tangential location (IND-FAB-3). White line at top left edge of pipe is the highlighted notch.

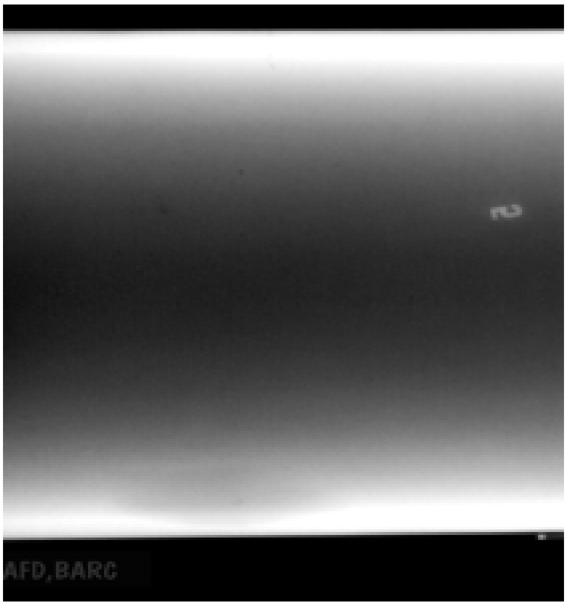


FIG. 7. Digital radiograph of pipe MAL-FAB-3 showing notch at edge.

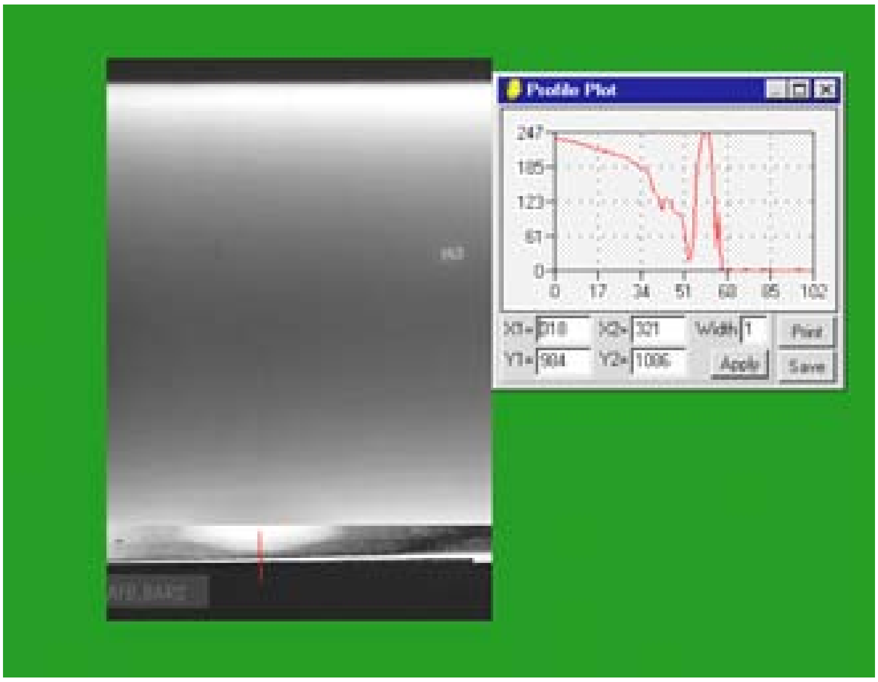


FIG. 8. Digital subtraction for ID defect (MAL-FAB-3) with profile plot.

(b) Profilometry

Wall thickness estimation was also done using the gray level profile across the pipe wall. As explained above, the thickness traversed by radiation has a particular profile. That rises abruptly at the ID tangent. A profile can be taken on the pipe in the wall area and thickness can be measured by counting the pixels in one wall thickness. Comparison of number of pixels in corroded wall thickness and the sound portion of the wall gives the measure of corrosion. If absolute value of remaining wall is to be found, pixel size is to be calibrated using a known thickness. That calibrated pixel size multiplied by number of pixels will give the wall thickness value.

The inset window in Fig 8 shows the profile plot which has a peak relevant to minimum wall. By counting pixels in the intact wall thickness, one can calibrate the remaining wall. Remaining wall with 12 pixels is about 25% of the total wall (45 pixel). In absolute terms this works out to be 1.7 mm. Direct observation on the film had revealed 1.5 to 3 mm as the least wall.

For DWDI radiographs profile is plotted for the step wedge in longitudinal direction to give grey level values on every step. That is compared with grey level on the dark patch of wall reduction to find the matching step. Even for scale deposit same method can be applied.

6. USE OF IMAGE PLATES

Imaging plate is a new type of phosphor (BaFBr:Eu), which has been used in medical field already. Its use in industrial RT field is yet to take off in a significant measure. This is because it is new and not much is known about their characteristics. Whatever is known, gives the idea that their dynamic range is very high but resolution is not so good. In a way these properties are complimentary to X ray films. Its computerized operation gives another advantage that of manipulation of the latitude. This last property is useful in the topic of present CRP. It helps viewing the middle zone of the pipe as well as at the tangential location, just by changing the viewing parameters.

Image plates were employed for locating artificial defects and measure the remaining wall thickness in our lab. The pipe was not from the set of round robin test, but specially made for the purpose. For 102 mm diameter pipe with 6.4mm wall thickness, X ray energies used was 60 and 80 kV respectively for DWDI and tangential exposures. Exposure was 15 mA sec, which is just 1/5th of the time a film would require. The picture in Fig 9 is tangential image with a fabricated notch. Inset window shows the procedure of digital subtraction. Fig 10 is the DWDI image for the same pipe with the inset showing the profile plot. Estimation of the notch depth can be done by comparison with the step-wedge.

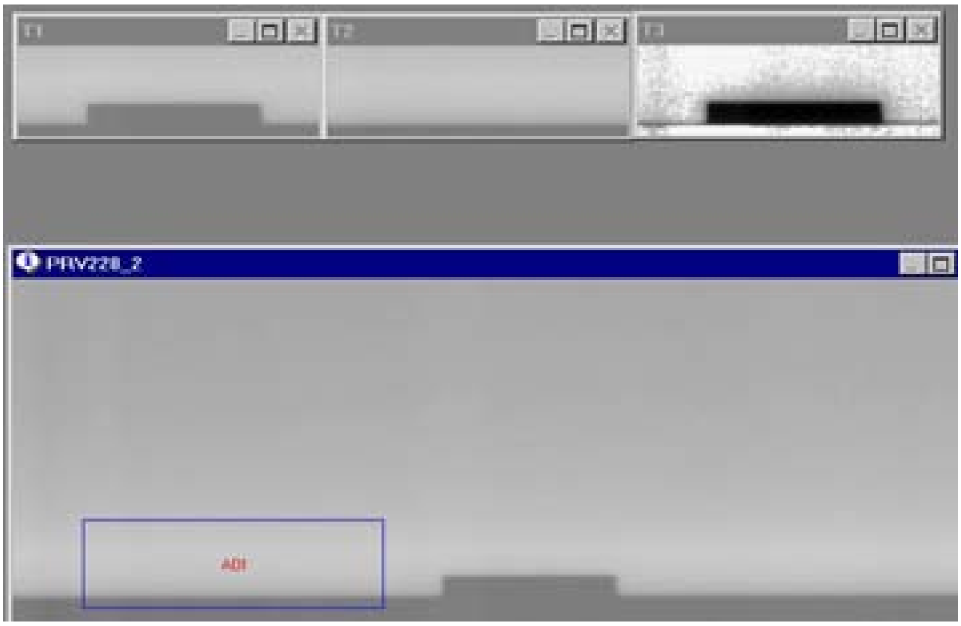


FIG. 9. Imaging plate picture: Notch in tangential location.

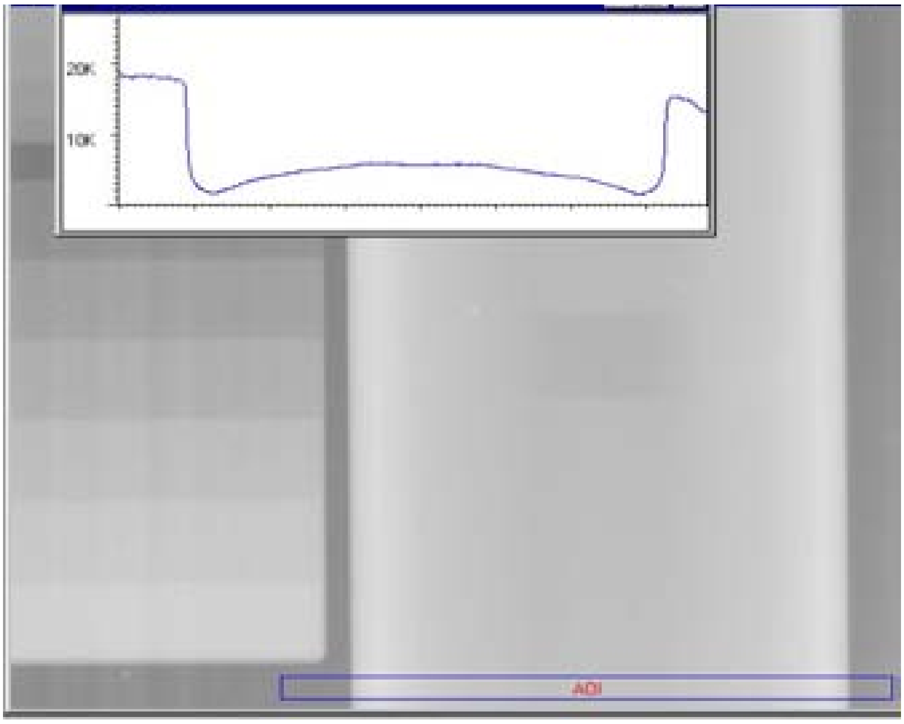


FIG. 10. Imaging plate picture with profile plot across the pipe diameter.

VALIDATION OF PROTOCOLS FOR CORROSION AND DEPOSIT EVALUATION IN PIPES BY RADIOGRAPHY

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Abstract

The objective of the project to propose and validate the protocol for corrosion and deposit evaluation in pipes by radiography. The tangential radiography technique was used to measure the remaining pipe thickness without removing its insulation material. The wall-shadow thickness was measured with a reasonable degree of accuracy. The film density and thickness correlation method was investigated to estimate the accuracy of measurement due to small change of thickness.

1. INTRODUCTION TO PROBLEM

Most of the chemical plant and refineries have pipes with diameter between 75 – 250 mm and the thickness range up to 50 mm. In Malaysia, the cold temperature pipes are insulated with calcium silicate material whereby the hot temperature pipes cover by polystyrene. The main problem of cold temperature pipe is water condensation and that would result material degradation (i.e. deposit and scale) inside the pipe and as well as between the insulation and pipe. Whereas for the hot temperature pipe the corrosion and erosion attack is occurred inside the pipe. To monitor this corrosion and deposit of insulated pipes, the radiographic technique has the advantages over other NDT techniques in term not removing the insulated material.

2. THEORETICAL CONSIDERATIONS

The tangential radiography technique is frequently used for the detection and evaluation of metal loss associated with pipe system erosion and corrosion. The technique makes possible to project a view the cross section of the pipe on the radiographic film making the direct measurement of the wall thickness. The extremities of the pipe wall cross section projected on the film may defined by lines drawn from the source of radiation to the film through tangential points on the inner and outer surfaces of the pipe. Therefore, radiation passes through is the chord of the outer surface that tangential to inner surface. More detailed of the basic principle of tangential radiography is explained by W.S. Bukle [3].

The image projected on the film is larger than actual thickness of the pipe wall. The enlargement depends on the source to film distance and the outer diameter of the corrected thickness of the pipe is given by:

$$W = Ws \text{ x } (SFD - 0.5 \text{ x}OD)/SFD$$

Where:

- W: wall thickness
- Ws: Wall-shadow thickness
- FFD: Focal to Film Distance
- OD: Outside diameter.

The penumbra or “unsharpness” is given by equation:

$$\text{and } Ug = 2(F \text{ x } 0.5OD)/(SFD-0.5OD)$$

Where:

- Ug: width of the total penumbra
- F: Radiation source focal spot

For determining the remaining wall thickness (W) of the pipe this equations are adopted.

3. EXPERIMENTAL SET UP AND PROCEDURES USED INCLUDING THE TEST PARAMETERS

a). Experimental set-up and procedure:

The experimental set-up for radiography was followed the guideline provided during the first CRP meeting in Turkey and also the general standard ISO 5579. All the experiment was executed at the facilities available of the NDT Group, Malaysia Institute for Nuclear Technology Research (MINT). Most of the radiography work was using X ray machine only since the gamma source of Iridium-192 is very low during the RRT samples were around.

First, all test pieces were subjected to 'full test' to detect if there is any imperfection the perimeter of pipes. In the second stage, the selected areas were radiographed using the tangential radiography technique for measuring the remaining wall thickness.

b) Wall thickness measurement.

Determination of remaining wall thickness in all test pieces is very difficult task. It is hard to measure the wall-shadow thickness with a reasonable degree of accuracy due to uneven inner surface. Therefore, the average of several measurement of the image of wall thickness was taken. In order to determine the thickness equation was adopted.

c) Round Robin Test (RRT)

Details of test specimens:

In this project, the test specimens have been prepared by three groups namely:

ASIA group (China, India, Rep. of Korea, Malaysia and Sri Lanka), MEDITERRANEAN group (Algeria, France, Syria, Tunisia, and Turkey) and Latin America group (Costa Rica).

For ASIA Group, it was agreed that each country participating in the Round Robin Test (RRT) must prepare at least 3 test pieces according to specified diameters either fabricated (FAB) or original (ORG) test pieces made of carbon steel.

The RRT schedule was beginning sometimes in early 1998 and Malaysia has received all test pieces from countries in the ASIA group. The detail of test pieces received is tabulated in Table I.

TABLE I. THE DETAIL TEST PIECES FROM THE NDT LABORATORIES IN THE ASIA GROUP.

No	Country	Type of Specimen	Identification	Outer Diameter OD (mm)	Pipe/Bend Thickness (mm)
1	Malaysia	ORG Pipe ORG Pipe FAB Pipe	M-ORG-01 M-ORG-02 M-FAB-03	69 69 69	7.4 7.4 7.4
2	PR China	FAB Pipe FAB Bend ORG Pipe ORG Pipe	PRC-FAB-01 PRC-FAB-02 PRC-ORG-01 PRC-ORG-01	114 105 50 30	8 6 4 4
3	Republic of Korea	FAB Pipe ORG Pipe Insulated FAB Pipe	KOR-1 KOR-2 KOR-3	60.6 60.6 60.6	4 5.6 4
4	India	Insulated FAB Bend Insulated FAB Pipe Insulated FAB Pipe Insulated FAB Pipe	IND-1 IND-2A IND-2B IND-3	50 74 90 168	7 8 7 6
5	Sri Lanka	Insulated ORG Pipe ORG Bend ORG Pipe	SL-1 SL-2 SL-3	45 65 120	5 3.9 6

4. CONCLUDING REMARK

In practical, the tangential radiography technique can be used to measure the remaining pipe thickness without removing its insulation material but the difficulty is to measure the wall-shadow thickness with a reasonable degree of accuracy due to even inner surface. Therefore, the film density and thickness correlation method should be explored in order to study the accuracy of measurement due to small change of thickness.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Report on First RCM of the CRP on Validation of protocols for corrosion and deposit determination in pipes by radiography (CORDEP), Istanbul, 15–19 September 1997.

[2] ISO 5579, Non-destructive testing — Radiography examination of metallic materials by X and gamma rays — Basic rules.

[3] BUKLE, W.S., Application of the tangential Radiographic technique for evaluating pipe system erosion/corrosion, Material Evaluation, Vol. 47, 1184–1188 (1986).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Report on Second RCM of the CRP on Validation of protocols for corrosion and deposit determination in pipes by radiography (CORDEP), Damascus, 17–20 May 1999.

VALIDATION OF PROTOCOLS FOR CORROSION AND DEPOSITS DETERMINATION IN SMALL DIAMETER PIPES BY RADIOGRAPHY

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Abstract

Tangential radiography was investigated to measure pipe thickness directly without removing its insulation material. But its measurement is restricted to tangential area of pipe and requires much more exposure time compared with film density - thickness relation method. Tangential radiography can be used for pipes less than 300 mm. In the proposed film density - thickness relation method, the experimental results were well agreed to the proposed relation in the range of film densities from 1.0 to 3.5. Therefore using the equation and experimentally determined parameters the quantitative evaluation of thickness variation is possible through the film density variation in the radiography of a sample exposed by radiation. It is found that gamma ray is a better radiation source compared with X ray in the quantitative thickness evaluation using film density variation. Film density - thickness relation method can also be used to measure pipe thickness indirectly without removing its insulation material.

1. INTRODUCTION

Ultrasonic methods are widely used in order to measure thickness of a pipe. Most of pipes in petrochemical plants are insulated to minimize heat loss and insulation should be removed to inspect them. Because the inspection is restricted to small area, it may be failed to detect locally corroded area by measuring thickness of sampled. But it will not be necessary to remove insulation and more it can enhance possibility to detect locally corroded area with radiography [1, 2]. Although the tangential radiography has some advantage, the measurement is restricted to tangentially contacted area of pipe. Therefore it might be required to inspect several times to inspect every area of pipe. To overcome this problem, film density-thickness correlation method is developed. Although radiographic imaging provides a two-dimensional image on inspection of a three-dimensional object, variation of the third dimension which is the thickness of object will be reflected by the density variation on the radiograph. In this paper tangential radiography and film density-thickness correlation method are introduced briefly.

2. TANGENTIAL RADIOGRAPHY

There are some important factors to be considered in tangential radiography, which are equivalent thickness for exposure, source to film distance (SFD) and thickness evaluation methods. Firstly, the equivalent thickness is a reference thickness to take the optimum exposure condition, which is long distance compared with nominal thickness of a pipe. It is the parameter necessary to bring about sharp contrast on a radiograph. Secondly, source to film distance is an accuracy related parameter in tangential radiography, which determines the geometrical unsharpness and measurement accuracy. Therefore it is required to take long SFD to obtain more accurate data in the tangential radiography. Finally, there are remained to evaluate a test result by the proper evaluation method at the situation.

Figure 1 shows the principle of tangential radiography for measuring pipe thickness, which is important parameter for evaluating corrosion and deposit in pipes.

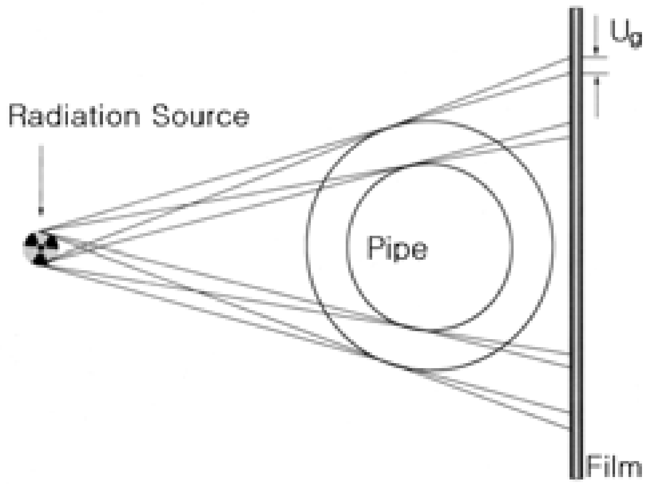

FIG. 1. Tangential radiography to measure pipe thickness.

Equivalent thickness for exposure

Equivalent thickness should be determined in advance of calculation of exposure condition. It increases with pipe size and require much more exposure compared with conventional radiography to inspect weld point of pipe. The maximum penetration thickness ($t_{\max}$) can be determined by geometrical consideration and it depends on outside and inside diameters of pipe,

$$t_{\max} = \sqrt{r_o^2 - r_i^2}$$

where r_o, r_i are outside and inside diameters, respectively. Normally reference thickness for exposure is taken by $t_{\max}/2$. Equivalent thicknesses for various sizes of pipes are listed in Table I.

TABLE I. REFERENCE THICKNESS FOR VARIOUS SIZES OF PIPES

Material	NPS (Pipe Size)	Schedule	Nominal thickness (mm)	Equivalent thickness for exposure (mm)
ASTM A53 (STPG 38-S) ASTM A312-TP340	2 inch (60.3 mm)	80	5.54	17.0
		40	3.91	14.0
	3 inch (88.9mm)	80	7.62	24.0
		40	5.49	21.0
	4 inch (114.3mm)	80	8.56	30.0
		40	6.02	25.0
	5 inch (141.3mm)	80	9.52	35.0
		40	6.55	29.0
	6 inch (168.3mm)	80	10.97	41.0
		40	7.11	33.0
	8 inch (219.1mm)	80	12.70	51.0
		40	8.18	41.0

Determination of source-film distance (SFD)

Because radiation source is not ideal point source, geometrical unsharpness is created on the radiograph as shown Fig. 1. The width of penumbra or geometrical unsharpness depends on the spot focal size of source, the SFD and the distance between object and film.

The adjustable parameter in field inspection is the SFD. As SFD increases, geometrical unsharpness decreases and therefore the measurement accuracy increases.

Total unsharpness is composed of geometrical, film and vibrational unsharpnesses [3]. Neglecting vibrational unsharpness caused by vibration of film or radiation source, total unsharpness is determined by film and geometrical unsharpnesses. In this case, it is not mere adding of them, but if $U_g \geq 2U_f$, then total unsharpness (U_t) becomes geometrical unsharpness (U_g), on contrary, if $U_f \geq 2U_g$, then total unsharpness (U_t) become film unsharpness (U_f), which is the minimum unsharpness [6] and depends on radiation source. But because practical testing will be conducted under $U_g \geq 2U_f$ in field inspection, total unsharpness will be determined by geometrical unsharpness. Therefore geometrical unsharpness of insulated pipe can be calculated as

$$U_g = \frac{s(0.5OD + d)}{SFD - (0.5OD + d)}$$

where d is the thickness of insulation material, OD is the outside diameter of pipe and s is spot focal size of radiation source. Therefore geometrical unsharpness decreases with SFD. In the condition of $U_f \geq 2U_g$, SFD is as follows:

$$SFD \geq (0.5OD + d)\left(1 + \frac{2s}{U_f}\right)$$

where, in the case of spot focal size 3.2 mm of Ir-192 , total unsharpness approaches to film unsharpness when the SFD becomes 20 times over of pipe's OD. But this is nearly impossible condition to obtain in the field.

On the other hand, if $U_g = U_f$, then $U_t = 1.3U_f$. Therefore constant unsharpness may be obtained as shown Table II and SFD is as follows.

$$SFD = (0.5OD + d)\left(1 + \frac{s}{U_f}\right)$$

In this condition, there is penumbra of $U_t = 1.3U_f$ on radiograph. This condition also requires much exposure time in the case of insulated pipe. So, to minimize the exposure time in field inspection, it is rather better to maintain U_g as a constant.

TABLE II. SOURCE-FILM DISTANCE (SFD) FOR TANGENTIAL RADIOGRAPHY.

Pipe size	SFD for non-insulated pipe (cm)		SFD for insulated pipe (cm)	
	$U_t = 1.3U_f$	$U_t = U_g$	$U_t = 1.3U_f$	$U_t = U_g$
2 inch	60.0	32.0	159.0	78.0
3 inch	88.0	47.0	187.0	91.0
4 inch	114.0	60.0	213.0	104.0
5 inch	140.0	74.0	239.0	118.0
6 inch	167.0		266.0	
8 inch	218.0		317.0	

Thickness Evaluation

Thickness evaluation is possible using geometrical calculation and the proportional method

Geometrical calculation

Given a geometrical condition, remaining wall thickness (t_w) may be calculated [1]:

$$t_w = t_a \frac{SFD - 0.5OD - d}{SFD}$$

where t_a is measured thickness on the radiograph, d is thickness of insulation material, OD is outside diameter of pipe, SFD is source to film distance.

Proportional method

When there is a large difference of dimension between the wall thickness and standard block, the proportion method is useful,

$$t_w = t_a \frac{B}{B_a - U_t}$$

where t_w is evaluated thickness, t_a is the measured thickness on the radiograph, B is a reference thickness of calibration block, B_a is the measured thickness on the radiograph[4].

3. DETERMINATION OF THICKNESS BY MEASURING DENSITY ON RADIOGRAPH

Radiographic imaging provides a two-dimensional image on inspection of a three-dimensional object. The third dimension is, however, reflected by the variation of the intensity of the X rays incident on the detector and depicted as film density variations on the exposed and developed radiograph. In a radiography exposed by poly-energetic X rays or gamma rays of a homogeneous object with varying thickness, film density variation may be correlated to the thickness variation [5].

Film density-thickness correlation method

Radiation intensity decreases exponentially as its penetration distance increases [6]. Based on the assumption that density increases exponentially with exposure in the industrial radiographic film, logarithmic film gradient which is a parameter representing the characteristic curve of a radiographic film is suggested. By combing these relations a new equation is developed, which represent the relation between density and thickness variation. Given an effective linear attenuation coefficient (μ_{eff}) and the logarithmic film gradient (δ), density variation may be expressed [2]:

$$x = x_s - \frac{5.31}{\delta\mu_{eff}} \log \frac{D}{D_s}$$

where x and D are unknown thickness and its measured density on radiograph, x_s is a known standard thickness, D_s is its measured density, which should be maintained as about 2.0.

4. TEST RESULTS AND DISCUSSION

The accuracy and reliability of the proposed relation has been tested using the radiographs of two carbon steel step wedge with known thickness variations. Film density decreases with thickness as shown in Fig. 2, which is a test result of carbon steel step wedge by X rays and at different exposure conditions. As thickness increases, the film density decreases more slowly, this resulted from beam hardening effect by polychromatic X rays. The conventional film density-thickness relation doesn't show linearity between thickness and density variations in the range of 1.0-3.5 of film density.

In Fig. 3, the same test results are displayed in logarithmic scale of the y-axis. This result demonstrates that the proposed relation reflects more accurately the film density-thickness variation on the radiographs. It is because of introduction of the logarithmic film gradient (δ), independent of film density in the above density range. The slowness of slope as exposure increases is due to beam hardening effect by increment of average thickness.

Fig. 4 is a test result by gamma ray (Ir-192) with different exposure conditions. There are absent of slope variation as shown in Fig. 3. It is because of relatively simple energy spectrum of gamma ray compared with poly-energetic X rays. In the case of Ir-192, gamma rays from 0.3 to 0.47 MeV energies make up about 90 % of all [15, 16]. Therefore, in the case of Ir-192, the change of effective linear absorption coefficient due to beam hardening effect may be slight compared with poly-energetic X ray.

Fig. 5 and 6 are thickness evaluation results using both the conventional relation and the proposed relation on the radiographs after testing two carbon steel step wedges by X and gamma ray respectively. As a result, it is found that the thickness evaluation using the proposed relation is more accurate than the conventional relation in both test results and gamma ray having simple energy spectrum is more effective radiation source in evaluating the thickness change through density variation on the radiographs.

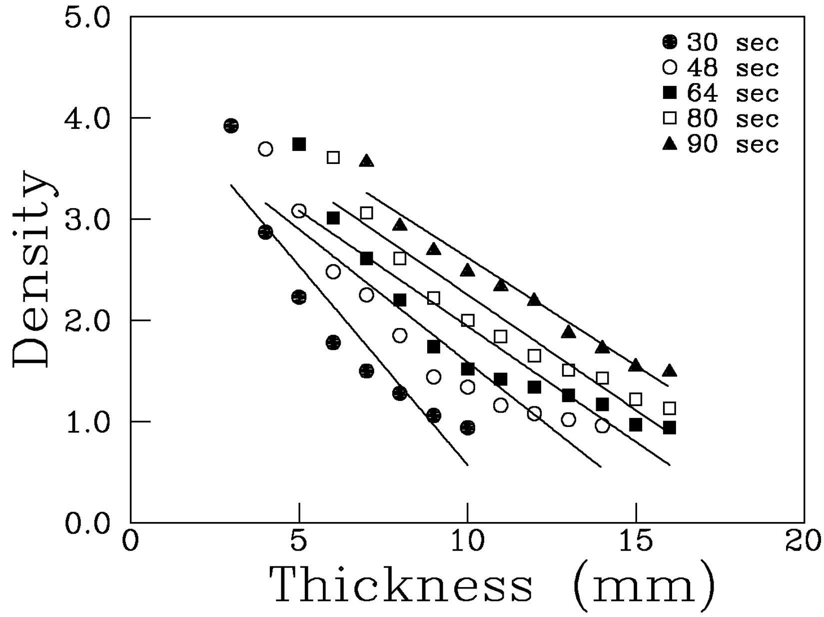

FIG. 2. Density variation versus thickness at different exposure condition with X ray.

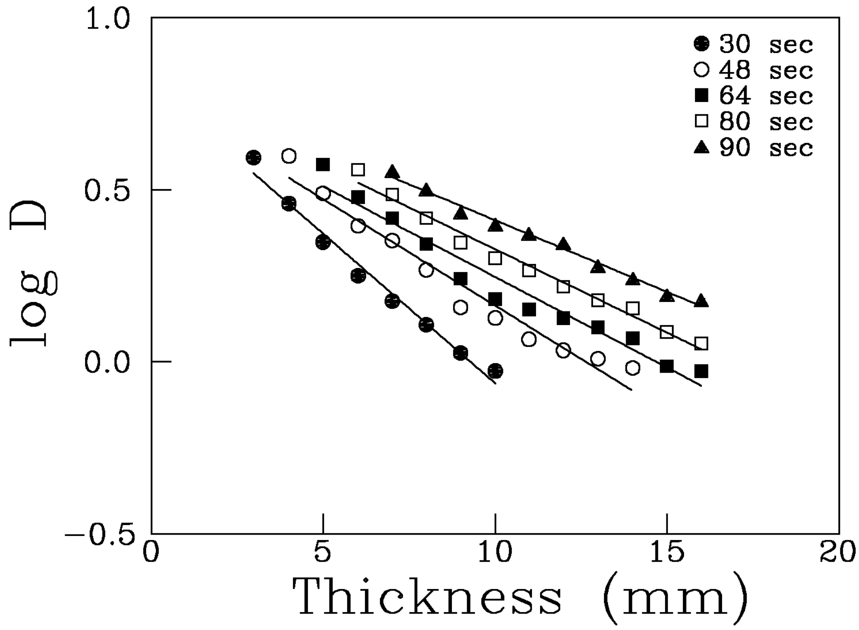

FIG. 3. Logarithmic density variation versus thickness at different exposure condition with X ray.

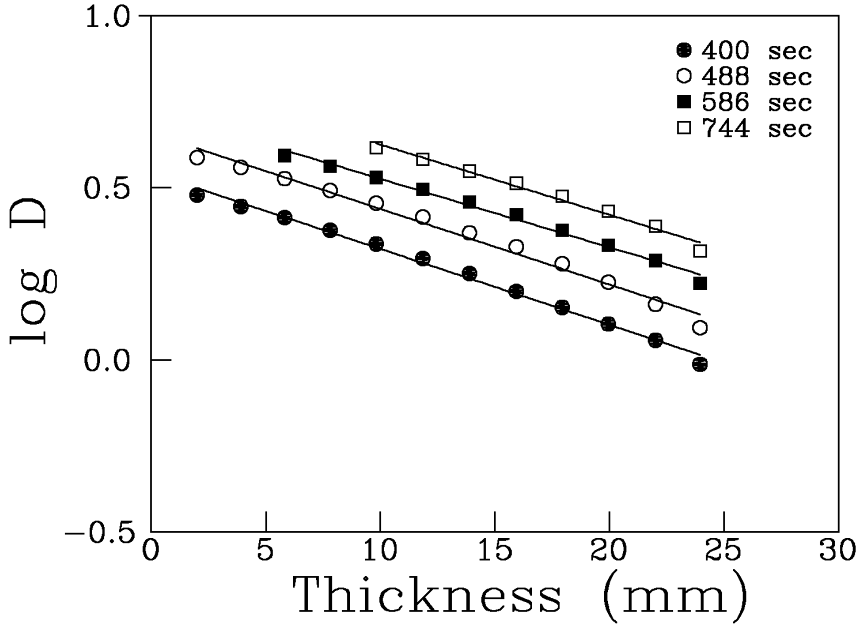

FIG. 4. Logarithmic density variation versus thickness at different exposure conditions with gamma ray.

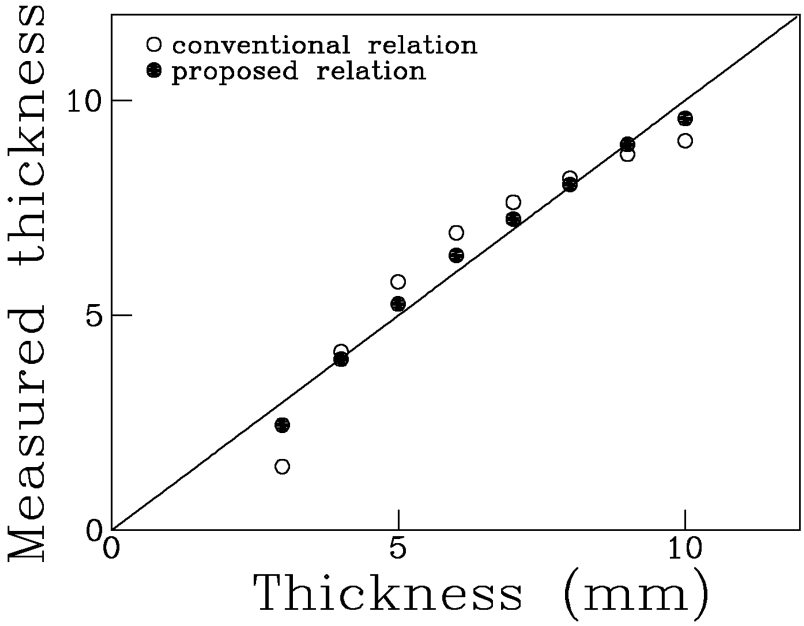

FIG. 5. Comparison of X ray test results evaluated by conventional and proposed relations respectively.

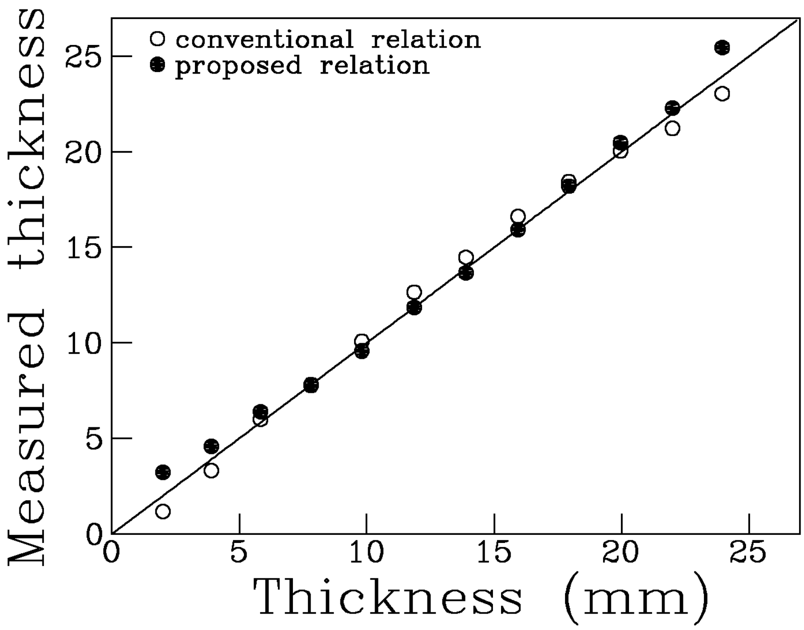

FIG. 6. Comparison of gamma ray test results evaluated by conventional and proposed relations respectively.

5. ROUND ROBIN TEST RESULTS

Round robin test results of test specimens from China, Rep. of Korea, Malaysia, India and Sri-Lanka are given in Table III. Quantitative determination of remaining wall thickness of every test specimens was done.

TABLE III. TEST RESULTS OF ROUND ROBIN TEST SPECIMENS

Specimen ID	**Specimen details**	**Tested by**	**Test parameters**	**Results**	**Remarks**
KOR-FAB-1	OD= 60.6 mm NT= 4 mm	KOR	Ir-192	T_{min} = 1.5mm	Artificial corrosions by electrochemical etching
KOR-FAB-2	OD= 60.6 mm NT= 5.6 mm	KOR	Ir-192	T_{min} = 1.8mm	Artificial corrosions by electrochemical etching
KOR-ORG-3	OD= 60.6 mm NT= 4 mm	KOR	Ir-192	Through hole	Natural corrosion General corrosion
IND-FAB-1 (sealed)	OD=50 mm NT=7 mm	KOR	IR-192	T_{min} = 4.9mm	
IND-ORG-2A (sealed)	OD=74 mm NT=6 mm	KOR	IR-192	3 corrosions	Deposit and 3 defects
IND-ORG-2B (sealed)	OD= 90 mm	KOR	IR-192	T_{min} = 2.0mm	Deposit
IND-FAB-3 (sealed)	OD=168 mm NT=6 mm	KOR	IR-192	4 rect. matched	4 rectangular fabricated metal loss
SRL-ORG-1	OD = 45mm L = 400 mm N.T = 5 mm	KOR	IR-192	T_{min} =0.4 mm	May be through hole
SRL-ORG-2	OD = 65 mm L = 136 mm N.T = 3.5 mm	KOR	IR-192	T_{min} =1.1 mm	
SRL-ORG-3	OD = 120 mm L = 360 mm N.T = 5.5mm	KOR	IR-192	T_{min} =0.4 mm	May be through hole Corrosion on outer surface
M-ORG-1	OD = 69 mm L = 350 mm N.T = 7.4mm	KOR	IR-192	T_{min} =1.2 mm	Deposit
M-ORG-2	OD = 69 mm L = 350 mm N.T = 7.4 mm	KOR	IR-192	T_{min} =6.6 mm	Light corrosion
M-FAB-3	OD = 69 mm L = 350 mm N.T = 7.4 mm	KOR	IR-192	T_{min} =3.6 mm	
PRC-FAB-1	Insulated pipe with deposit OD = 114 mm	KOR	IR-192	T_{min} =3.9 mm	Artificial defects with difference depth
PRC-FAB-2	Insulated elbow OD = 105 mm	KOR	IR-192	T_{min} =3.5 mm	Artificial defects with difference depth

Specimen ID	Specimen details	Tested by	Test parameters	Results	Remarks
PRC-ORG-1	Insulated pipe OD = 50 mm	KOR	IR-192	T_{min} =3.3mm	natural corrosion
PRC-ORG-2	Insulated elbow OD = 30 mm	KOR	IR-192	T_{min} =3.3mm	natural corrosion

4. CONCLUSIONS

- Tangential radiography can be used to measure pipe thickness directly without removing its insulation material. But its measurement is restricted to tangential area of pipe and requires much more exposure time compared with film density-thickness relation method.
- Tangential radiography can be used for pipe diameter less than 300 mm.
- In the proposed film density-thickness relation method, the experimental results were well agreed to the proposed relation in the range of film densities from 1.0 to 3.5. Therefore using the equation and experimentally determined parameters the quantitative evaluation of thickness variation is possible through the film density variation in the radiography of a sample exposed by radiation.
- It is found that gamma ray is a better radiation source compared with X ray in the quantitative thickness evaluation using film density variation.
- Film density-thickness relation method can also be used to measure pipe thickness indirectly without removing its insulation material.

REFERENCES

[1] LEE, S.S., LEE, J. K., KIM, Y.H., "Thickness evaluation using tangential radiography," Journal of the Korean Society for Non-destructive Testing, Vol. 18, No. 3, (1998) 205–210.

[2] BURKLE, W. S., "Application of the tangential radiographic technique for evaluating pipe system erosion/corrosion," Material Evaluation. Vol. 47, ASNT, (1989) 1184–1188.

[3] INDUSTRIAL RADIOGRAPHY, Agfa-Gevaert N.V. 1986, pp.67–72.

[4] KROLICKI R.P., "Gamma-radiography of high temperature and corroded objects," Material Evaluation. Vol. 43, ASNT (1985) 1008–1012.

[5] LEE, S.S., LEE, J. K., KIM, Y.H., A Study on Thickness Evaluation Using Radiography, the Korean Society for Non-destructive Testing.

[6] McMASTER, R. C., eds. Non-destructive Testing Handbook Vol. 1, pp. 1915–1916.

VALIDATION OF PROTOCOLS FOR CORROSION AND DEPOSIT DETERMINATION IN PIPES BY RADIOGRAPHY "CORDEP"

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Abstract

The CRP aimed at developing radiographic protocols and instructions for identification and measurement of the corrosion attack and deposits in pipes (across insulation) in industrial installations during operation (on-line and in maintenance). The CRP addressed the needs of end-users in terms of developing reliable and appropriate NDT measurement protocols which should refer to general requirements of international standards with full implementation of recognized quality assurance methodologies. The general scope of the CRP covered radiographic measurements of corrosion and deposit in straight pipes and bends made of carbon or stainless steel corroded/eroded on the outer or/and inner surface without insulation or having thermal or/and bituminous insulation covering outer diameter of pipe (external insulation), in petroleum and gas industry, in water installations. The results of radiographic testing were verified by ultrasonic measurements and by destructive testing when appropriate.

1. INTRODUCTION TO THE PROBLEM

Piping is the most common way of transporting liquids and gases for industrial purposes and use of such piping has been rapidly increasing in the past as a result of industrial development. Piping used for transporting liquids and gases under high temperature are covered with thick insulating material for conservation of heat.

Corrosion that can occur on the inside and outside surfaces of the pipes will reduce the effective thickness of the pipe walls. Deposits inside the pipe surface will result in either reducing or completely blocking the flow through the pipes. Therefore, it is essential to monitor such pipes to detect changes in the wall thickness and presence of deposits inside the pipes.

2. THEORETICAL CONSIDERATIONS

Tangential Radiography makes it possible to project a view of the cross section of the pipe onto photographic film making the direct measurement of the wall thickness possible. The extremities of the pipe wall cross section projected onto the film may be defined by lines drawn from the source of radiation to the film through tangential points on the inner and outer surfaces of the pipe. Therefore the thickest portion of the pipe through which the radiation passes through is the chord of the outer surface that is tangential to the inner surface.

The image projected onto the film is larger than the actual thickness of the pipe walls (Figure 1). The enlargement depends on the source to film distance and the outer diameter of the pipe. It can be easily shown that the corrected (actual) thickness of the pipe is given by,

$$T_c = T_a\,(SFD - 0.5d)/SFD$$

Where

- T_c = Corrected thickness of the pipe
- T_a = apparent thickness of the pipe
- SFD = source to film distance
- d = outer diameter of the pipe

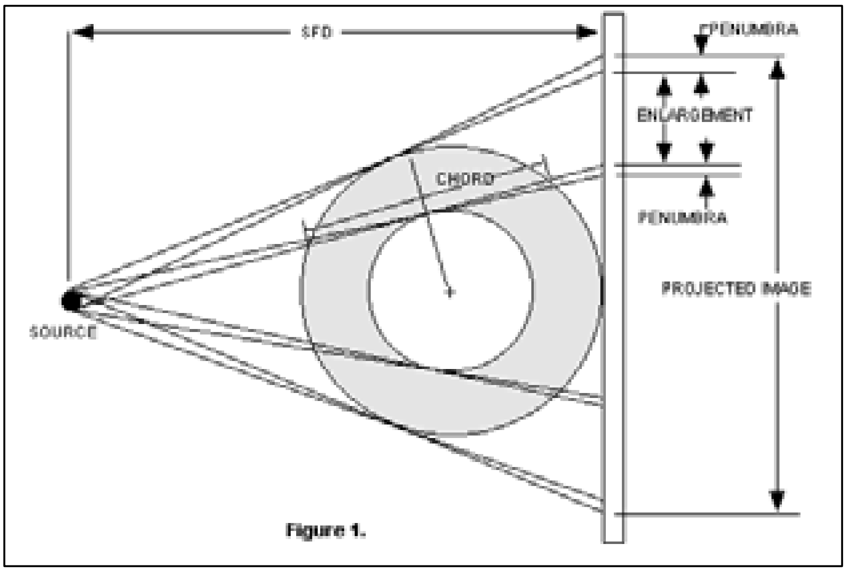

FIG. 1. Principle of the tangential radiography.

As the radiation does not actually emanate from a point source but from a source with finite dimensions, a penumbra (shadow image of the edges of the cross section) will also appear on the film.

The extent of the penumbra (so called "unsharpness") may be calculated as follows, and a further correction may be made to the wall thickness using it.

$$U_g = F\ d\ /\ (SFD - 0.5d)$$

where

- U_g= total width of penumbra ("unsharpness")
- F = focal spot size of the radiation source

Exposure calculations:

- Maximum penetration thickness of radiation: $T = 2\sqrt{d^2 - d_i^2}$

- Reference thickness for exposure: $1/2T = \sqrt{d^2 - d_i^2}$

where:

- d = outside diameter;
- di = inside diameter

3. EXPERIMENTAL RESULTS

National NDT laboratory of Sri Lanka cooperated in round robin test (RRT) among Asia participants in this CRP. Three original specimens were prepared and evaluated. Table I and II presents the details of test specimens and results obtained using tangential radiography.

TABLE I. DETAILS OF TEST SPECIMENS

Country of origin	*Specimen No.*	*Outside diameter OD (mm)*	*Nominal thickness NT (mm)*	*Length L (mm)*	*Type of specimen*
Malaysia	M-ORG-1	69	7.4	350	Straight pipe
	M-ORG-2	69	7.4	350	Straight pipe
	M-FAB-3	69	7.4	395	Straight pipe
India	IND-FAB-1	50	7		Insulated bend
	IND-FAB-2A	74	8	200	Insulated pipe
	IND-ORG-2B	90	7	200	Insulated pipe
	IND-FAB-3	168	6	202	Insulated pipe
Sri Lanka	SRL-ORG -1	45	5	400	Insulated pipe
	SRL-ORG-2	65	3.9	135	Bend
	SRL-ORG-3	120	6.0	360	Pipe
China	PRC-FAB-1	114	8		Insulated pipe
	PRC-FAB-2	105	6		Insulated elbow
	PRC-ORG-1	50	4		Insulated pipe
	PRC-ORG-2	30	4		Insulated elbow
Korea	KOR-FAB-1	60.6	4	300	Straight pipe
	KOR-FAB-2	60.6	5.6		Insulated pipe
	KOR-FAB-3	60.6	4		Elbow

TABLE II. THICKNESS MEASUREMENT BY TANGENTIAL RADIOGRAPHY METHOD

Specimen No.	**Specimen Details**	**Test Parameters**	**Results: Minimal Thick T_{min} (mm)**	**Remarks**
SRL-ORG-1	Insulated Pipe. OD = 45mm, N.T.= 5 mm	X ray; kV: 250, mA: 4, SFD= 635mm	2.2	Uniform corrosion
SRL-ORG-2	Bend OD = 65mm, N.T. = 3.9 mm	X ray; kV: 250, mA: 4 , SFD= 635mm	1.6	High corrosion
SRL-ORG-3	Pipe OD = 120 mm, N.T. = 6.0 mm	X ray; kV: 150, mA: 5, SFD= 260 mm	2.5	High corrosion
M-ORG-1	Pipe OD = 69 mm, N.T. = 7.4mm	X ray; kV: 150 , mA: 5, SFD= 350 mm	2.2	Deposit / scale
M-ORG-2	Pipe OD = 69 mm, N.T.= 7.4 mm	X ray; kV: 150, mA: 5, SFD= 350mm	6.0	Light corrosion
M-FAB-3	Pipe OD = 69 mm, N.T. = 7.4 mm	X ray; kV: 150 , mA: 5 , SFD= 350 mm	3.0	Light bend/patch

Specimen No.	Specimen Details	Test Parameters	Results: Minimal Thick T_{min} (mm)	Remarks
PRC-ORG-1	Insulated straight pipe OD = 50 mm, NT = 4 mm	X ray; kV: 250, mA: 5 , SFD= 625mm	2.5	Uniform Corrosion
PRC-ORG-2	Insulated bend OD = 30mm, NT = 4 mm	X ray; kV: 250, mA: 5, SFD= 625mm	2.8	Uniform corrosion
PRC-FAB-1	Insulated straight pipe OD = 114mm, NT = 8 mm	X ray; kV: 300, mA: 4, SFD= 635mm	3.8	Pitting
PRC-FAB-2	Insulated bend OD = 105mm, NT = 6 mm	X ray; kV: 250, mA: 5, SFD= 625mm	4.6	—
KOR-FAB-1	Pipe OD = 60.6mm, N.T. = 4 mm	X ray; kV: 250, mA: 5 SFD= 625mm	1.5	Pitting/ corrosion
KOR-FAB-2	Insulated pipe OD = 60.6mm, N.T. = 5.6mm	X ray; kV: 300, mA: 4, SFD= 635mm	3.5	Through hole
KOR-ORG-3	Elbow OD = 60.6mm, N.T. = 4 mm	X ray; kV: 300, mA:4, SFD= 635mm	1.6	Corrosion/ through hole
IND-FAB-1	Elbow with insulation OD = 50mm, N.T. = 7mm	X ray; kV: 250, mA: 5, SFD= 625mm	5.2	—
IND-FAB-2A	Pipe with insulation OD = 74mm, N.T. = 8mm	X ray; kV: 300, mA: 4, SFD= 635mm	4.6	—
IND-ORG-2B	Pipe with insulation OD = 90mm, N.T. = 7mm	X ray; kV: 300, mA: 4, SFD= 635mm	2.4	—
IND-FAB-3	Pipe with insulation OD = 168mm, N.T. = 6mm	X ray; kV: 300, mA: 4, SFD= 635mm	4.1	—

4. CONCLUSION

Tangential radiography method can be used to measure remaining wall thickness of insulated and non-insulated pipes with a reasonable degree of accuracy. Average value of several wall shadow thicknesses has to be taken for corrected thickness measurement. The method can be used also for measurement of deposit in straight pipes.

REFERENCES

[1] Draft reports of first and second RCM on validation of protocols for corrosion and deposit determination in pipes by radiography.
[2] ISO 5579 – Radiographic testing basic rules.
[3] ISO 1106/3 – Radiographic testing of circumferential welds in pipes.

EVALUATION OF CORROSION AND DEPOSIT IN PIPES BY RADIOGRAPHY

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Abstract

This report contains the results of the tangential radiography technique applied for detection and evaluation of internal and external corrosion, deposit thickness and pits occur in the insulated and non insulated pipes. Also, measurement of the remaining wall thicknesses can be obtained by this technique. A comparison between the measurement results obtained by tangential radiography and ultrasonic and destructive testing on the same pipes has shown identical results. These results confirm, with high accuracy, that the tangential radiography can be practically applied for evaluation the current condition of the insulated and non insulated pipes.

1. INTRODUCTION

The reliability and safety of industrial equipment, especially in petroleum industry and power plants, are substantially influenced by degradation processes such as corrosion, erosion, deposits and blocking of pipes which might cause fire, leaks, low production, or unpredictable and costly shutdown due to the need of repair and replacement.

Determining the extent and the progress rate of the corrosion and deposit provide useful information about the operation life and safety [1, 2]. Many of non-destructive test methods can be used to some extent for corrosion evaluations, among them, tangential radiography and radiograph density variation measurements which can be used as a third dimension of a homogenous object with varying thickness and can be correlated to the thickness variation [3].

2. TEST PIECES

Each country participating in this project had to prepare three test pieces made of carbon steel either original (ORG) or fabricated (FAB). In our NDT laboratory we had prepared, as planed, three round robin test specimens. Two of them are fabricated steel pipes and the third one is a steel elbow. The first fabricated specimen is a straight pipe of 100 mm internal diameter, 300 mm length and 5 mm wall thickness with three internal slots to simulate internal regular corrosion. The second one is also straight pipe of 100mm internal diameter, 300mm length and 4mm wall thickness with three internal slots to simulate internal regular corrosion and two external slots to simulate the external regular corrosion. This specimen was covered with 5mm thick fiber glass insulator. The third specimen is an original elbow, taken from electrical power generation plant; this corroded elbow contains a part of smaller elbow and two weldments.

The Syrian NDT laboratory being a member of the Mediterranean group had received three specimens sent from Turkey. The first specimen is a fabricated straight pipe without insulation, the second is an original straight pipe with insulation and the third is an elbow. The laboratory had also received three original straight steel pipes with internal defect from France and two other straight pipes sent from the Algerian participating laboratory. One of them a straight pipe with internal defects and the other one an elbow with internal defects and corrosion. Finally the laboratory had received one original straight steel pipe with internal defect and corrosion from Tunisia.

The detail of the above mentioned test pieces are tabulated in the following table I.

TABLE I. DETAILS OF TEST PIECES

No.	Country	Type of Specimen	Identification	Outer diameter OD [mm]	Nominal Thickness NT [mm]	Length L [mm]
1	Syria	ORG. Elbow FAB. Pipe FAB. Pipe	SYR.O1 SYR.F1 SYR.F2	110 110 110	4 5 4	Elbow 300 300
2	Turkey	ORG. Pipe FAB. Elbow FAB. Insulated pipe	TUR - ORG P3 TUR - FAB - E2 TUR - FAB - P1	60 60 60	3.5 4 4	300 elbow 300
3	France	ORG. Pipe ORG. Pipe ORG. Pipe	FRA1 FRA2 FRA3	60 115 166	4 6.5 7.5	300 300 310
4	Algeria	ORG. Elbow ORG. Pipe	ALG1 ALG2	100 168	4.2 6.4	Elbow 230
5	Tunisia	ORG. Pipe ORG. Pipe ORG. Pipe	TUN 1 TUN 2 TUN 3	60 100 150	4 6.5 4	257

3. THEORETICAL CONSIDERATIONS

Tangential Radiography is a powerful method for corrosion and deposit measurements. Many authors had reported the application of tangential radiography testing methods for determination the existence of corrosion in pipes and measuring their remaining wall thickness using numerical calculation or using calibration blocks [4, 5]. The principle arrangement of the tangential radiography technique is shown in figure 1.

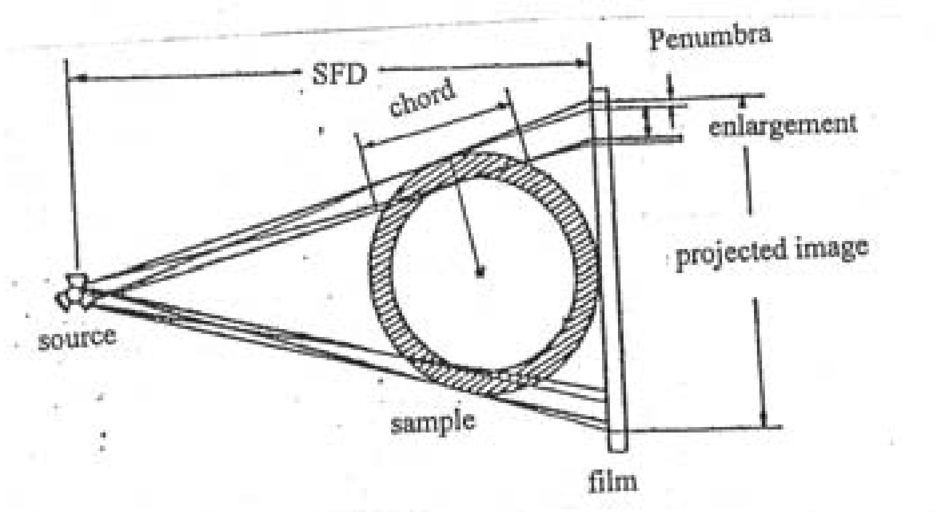

FIG. 1. Tangential Radiography technique.

In tangential radiography the maximum penetration thickness can be determined by geometrical consideration and it depends on outside and inside diameters of the pipe. Normally the value of the thickness for exposure is taken to be equal to the half of the maximum penetration thickness.

The cross section of the pipe wall that appears on the film is approximately that which occurs perpendicular to the center of the chord [6]. As the image of the cross section is projected on to the film, the image is enlarged somewhat. This enlargement is proportional to the source to film distance and source to object distance and it may be readily calculated and taken into consideration in the direct wall measurement as follows:

$$I_c = \frac{I_a(SFD - 0.5d)}{SFD}$$

Where:

- I_c = wall thickness
- I_a = wall – shadow thickness
- SFD = Source to film distance.
- d = outside diameter of pipe

Because the radiation does not actually emanate from a point source, a penumbra (shadow image of the edges of the cross section) will also appear on the film. The extend of the penumbra (so called "unsharpness") may be calculated by the following equation, and a further correction may be made in the direct wall reading:

$$U_g = \frac{2 \cdot (F \times 0.5d)}{(SFD - 0.5d)}$$

where:

- U_g= width of the total penumbra ("unsharpness")
- F = radiation source focal spot size.

The remaining thickness of the pipe wall can also be calculated by applying the proportional method concept using a reference block. When the reference block is properly placed on the test object during exposure, on the pipe's outside diameter tangent point, it would provide an easily method for the pipe's remaining wall thickness evaluation by using the following equation:

$$I_c = I_a \frac{B_C}{B_a}$$

Where:

- B_c = reference width of the scale most closer to wall – thickness among v scales contained in the reference block
- B_a = the shadow of B_c on the radiograph.

Film type and exposure density are significantly influence the accuracy of tangential radiography.

4. EXPERIMENTAL SET UP AND PROCEDURES USED

All test specimens from France, Turkey, Algeria, Tunisia, and Syria had examined according to the written procedures prepared by following the international standard ISO 5579. Tangential radiography by applying the proportional method, double wall one image and double wall double image techniques were applied during examination to determine the remaining wall thickness of the test specimens and to localize the exact position of the flaws and pits [7].

Pit depths had been determined by measuring the radiographic densities of the sound and pitted areas using density thickness curves. The density thickness curve had established by exposing a stepped block having the same material, as the tested specimen, and covering the thickness range up to twice of the specimen's wall, and then correlating the thickness with densities of each step. Each density thickness curve represents only one condition of film type, radiation energy and material. The stepped block and the specimen can be exposed either together on the same film or separately but under the same condition.

A number of tangential radiographs were produced for the above mentioned specimen at source to film distance (SFD) equal to 10 times the pipe's outer diameter [6]. Exposures were made using fine grain Kodak AX film type and 0.125 mm thick lead screens, front and back. The films were exposed to a density of 2.0. Each exposure time was calculated at the basis of half original length of the chord passing through the ID tangent point and the applied SFD. Exposures were made using Iridium – 192 radio isotope with focal spot size of (2.5 x 2.5) mm or using Gilardoni X ray machine (80 – 200) kV with focal spot size of (2.3 x 2.3) mm. After exposure, the films were processed and dried in a strict procedure in accordance with the manufacturer's recommendations.

5. RESULTS AND DISCUSSION

The results of radiography testing, of Syrian specimens, were verified firstly by ultrasonic testing method then by destructive testing.

The wall thickness of the two fabricated steel pipes and the elbow were measured by ultrasonic (pulse echo technique, longitudinal wave) with 100% surface scanning using equipment with the data shown in table II.

TABLE II. ULTRASONIC TESTING OF SPECIMEN

Ultrasonic flaw detector type	Krautkramer Branson USL 48 No. 25690 – 4393
Probe	Duel crystal probe Frequency 4 M Hz Crystal size 3.5 x 10
Calibration blocks	Krautkramer steel stepped block having 8 steps from 1 to 8 mm
Coublant	Motor oil

After carrying out the ultrasonic measurement, each one of the pipes was axially cut by electrical saw and the thickness of its different areas were measured by mechanical methods. The results of ultrasonic and destructive testing methods are shown in the table III.

By comparing the result of measurements obtained by tangential radiography of the most corroded area exist in each of the three Syrian specimen with the result obtained by ultrasonic testing method and destructive method for the same specimen we fond out that the results were almost identical.

TABLE III. RESULTS OF ROUND ROBIN TEST

Specimen	Location	Nominal wall thickness measurements by ultrasonic method [mm]	Nominal wall thickness measurements by destructive methods [mm]
SYR.F1 Pipe with regular internal corrosion	From 0 to 55 [mm]	5	5
	From 55 to 85 [mm]	3	3.1
	From 85 to 130 [mm]	5	5.1
	From 130 to 160 [mm]	2	2
	From 160 to 235 [mm]	5	5.1
	From 235 to 300 [mm]	3	3
SYR. F2 Pipe with regular internal and external corrosion	From 0 to 20 [mm]	4	4.1
	From 20 to 45 [mm] Internal corrosion	2	2.1
	From 45 to 60 [mm]	4	4
	From 60 to 80 [mm] External corrosion	2	2
	From 80 to 110 [mm]	4	4.1
	From 110 to 135 [mm] Internal corrosion	2	2
	From 135 to 175 [mm]	4	4.1
	From 175 to 200 [mm] External corrosion	2	2.1
	From 200 to 240 [mm]	4	4
	From 240 to 275 [mm] Internal corrosion	2	2
	From 275 to 300 [mm] Internal corrosion	3.5	3.5
SYR. O1 Elbow with part of smaller internal welded elbow inside it	Pipe body	4	4
	Internal welded elbow	5	5
	Corroded area	3.5	3.5

6. CONCLUSION

The results of this work have shown that tangential radiography is an accurate method for the determination of the remaining wall thickness, deposit thickness and pits depths in non insulated and insulated specimens. Density measurement technique can also be applied as an alternative method to measure pit depths and remaining wall thickness for non-insulated or insulated specimens without removing its insulation material.

REFERENCES

[1] HERBERT H. UHLIG, R. Wincton review, Corrosion and Corrosion Control, 3ed edition, John Wiley & Sons, Inc, N. Y. (1985) 165–186.
[2] FONTANA M., Corrosion Engineering, 3ed edition, Mc.Graw - Hill, Inc., N.Y., (1986) 220–256.
[3] GRIFFITHS R., Over View of Oil Refinery Corrosion Monitoring, Non - Destructive Testing, Australia Vol. 26, No. 1, (1989)
[4] KENNETH BILLEAUDEAUX J., Tangential Radiography Using a Radiation Gage, Materials Evaluation, February 1992
[5] KROLICKI R.P., Internal Corrosion Examination and Wall Thickness Measurement of pipe by Radiographic Method, Material Evaluation, February 1977.
[6] BURKLE W.S., Application of the Tangential Radiographic Technique for evaluating pipe system Erosion/ Corrosion, Materials Evaluation, October (1989)
[7] HALMSHAW R., Industrial Radiology, 2nd edition, Chapman & Hall, London (1995).

VALIDATION OF PROTOCOLS FOR CORROSION AND DEPOSIT EVALUATION IN PIPES BY RADIOGRAPHY

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Abstract

The objective was to propose and to validate standard protocols for corrosion and deposit evaluation in pipes by film based tangential radiography. Film density measurement technique had to be used as an alternative or complementary method. The CRP covered straight pipes and bends/elbows made of carbon steel corroded/eroded on the outer or/and inner surface with or without insulation, some of them with deposit inside the pipe. This kind of a research work was co-ordinated as a Round Robin Test (RRT) programme. For the RRT, Turkey prepared three test samples of diameter 60 mm and wall thickness 4 mm, one straight pipe including artificial flaws and deposit, one elbow with artificial wall thinning and one straight pipe including natural corrosion pits. The examination procedures for the RRT samples were prepared by taking the General Standard ISO 5579 into consideration, and the examinations carried out accordingly. Aside from the RRT programme, Turkey prepared a draft standard on the subject for submission to ISO as a standard proposal.

1. INTRODUCTION

Pipelines in petroleum industry, power plants, water networks and other sectors are vulnerable to internal and external corrosion and erosion, and subjected to deposit accumulation. Determination the extent and the progress rate of corrosion and deposit by the NDT methods even while the plant is in operation provides useful information about the operational life of the components and safety.

The wall thickness in a pipeline is the most important parameter to be monitored and measured. Radiography assures the inspection of the pipe without removal of insulation during operation of the plant and is even applied in high temperature environments. Radiography is also an effective NDT method for the evaluation of deposit.

The use of tangential film based radiography is already known for a long time and many studies on this subject have been reported. However, there are no standardized protocols and recommended practices for these particular radiographic tests.

This CRP was proposed to validate standard protocols for corrosion and deposit evaluation in pipes by film based tangential radiography. Film density measurement technique should be used as an alternative or complementary method.

The CRP covered small diameter (up to 6 inches outside diameter) straight pipes and bends/elbows, as fabricated and original (corroded) and with or without deposit. The results of the radiographic testing were verified by ultrasonic method and by mechanical measurements. Basing on the experiences and results obtained by radiographic examinations and that discussed in the 2nd RCM, a draft standard, which is parallel to ISO 5579 was prepared in order to discuss in the 3rd RCM and then submit to the technical committee of ISO.

2. ROUND ROBIN TEST PIECES

Round Robin Test (RRT) was the main part of this CRP. A detailed work plan of the project and of the RRT programme was prepared in the 1st RCM held at Çekmece Nuclear Research and Training Center in Istanbul, 15–19 September 1997.

The participating countries were divided into three regional groups in order to avoid excessive duration and costs of transportation of specimens. Turkey was in the Mediterranean group together with France, Syria, Tunisia and Algeria. Each participant in the group had to test its own RRT samples first and then to transfer them to the next country. The diameter range of the samples was between 1-6 inches.

Turkey prepared the following types, number and dimensions of RRT test pieces:

- One fabricated straight pipe of 60 mm diameter, 4 mm wall thickness and 300 mm length, made of carbon steel, including various artificial flaws, deposit and external insulation (see figure 1).
- One fabricated elbow of 60 mm diameter, 4 mm wall thickness, made of carbon steel and including artificial flaws representing wall thinning (see figure 2)
- One natural straight pipe of 60 mm diameter, 3.5 mm wall thickness and 300 mm length, made of carbon steel including natural corrosion pits on the outside surface and provided from a heat station (see figure 3).

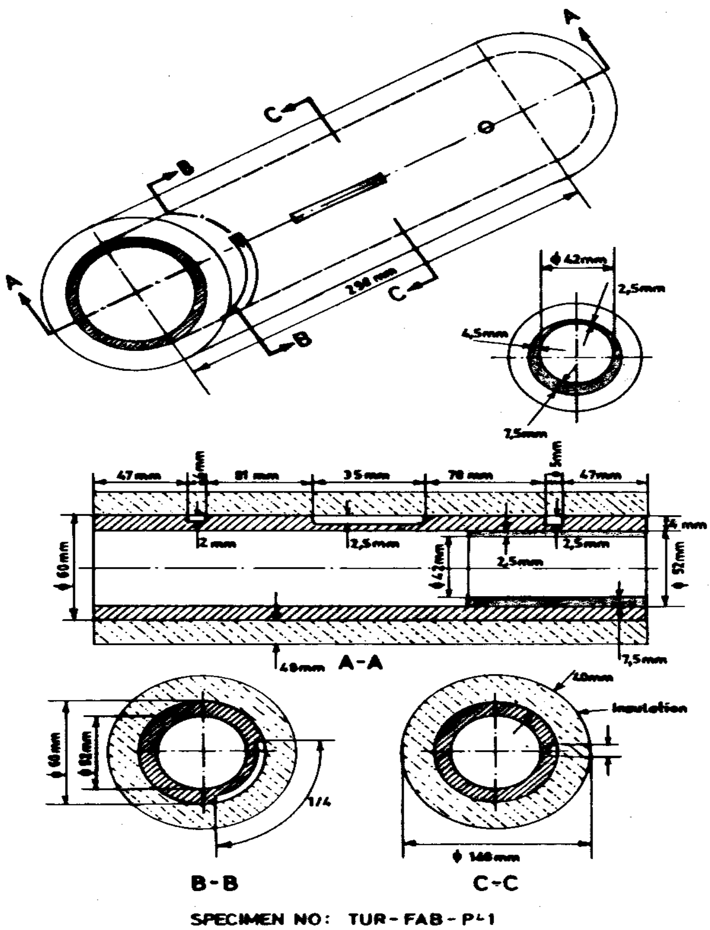

FIG. 1. Fabricated straight pipe.

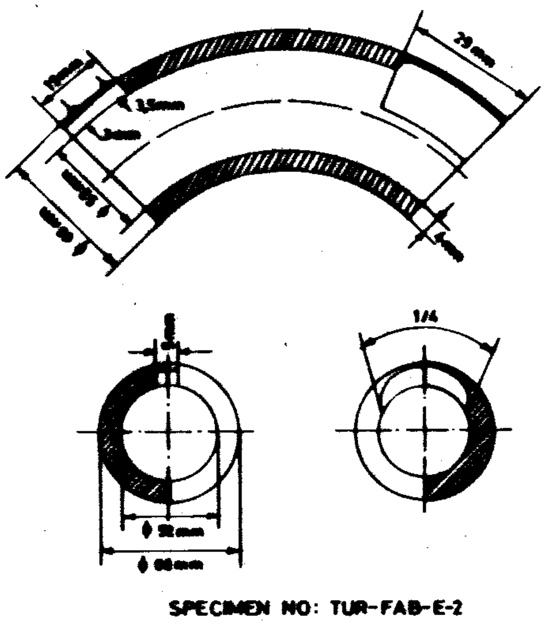

FIG. 2. Fabricated elbow .

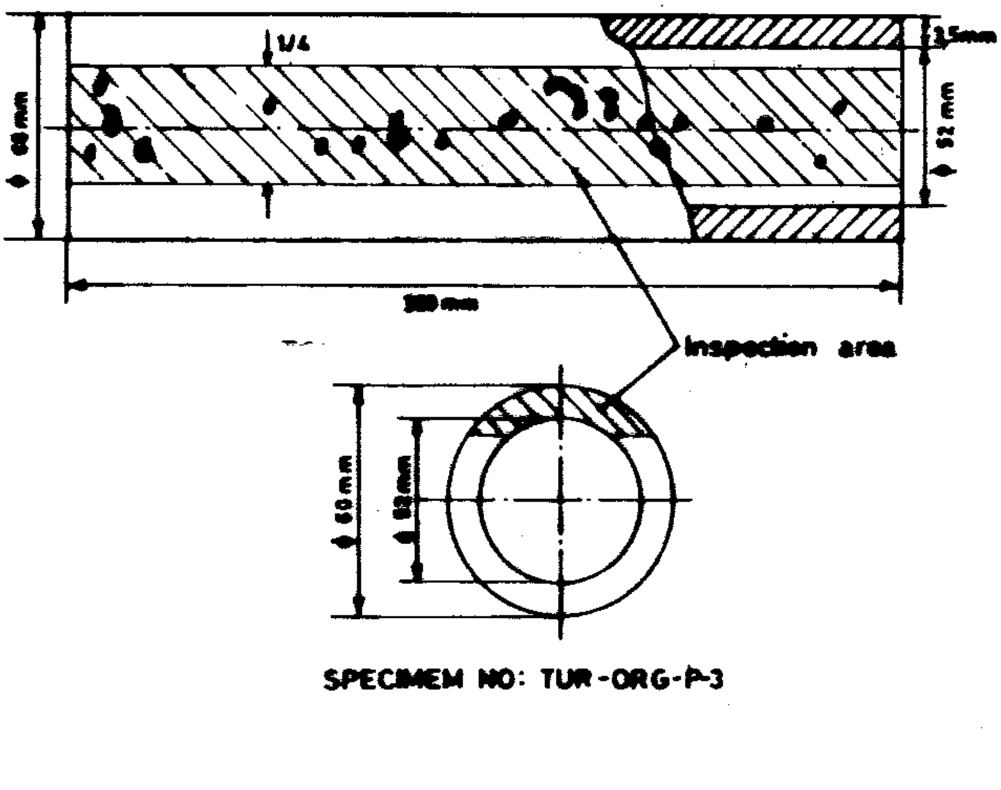

FIG. 3. Natural straight pipe

3. THEORETICAL CONSIDERATIONS

Radiographic methods can be accurately applied for the determination of pipe wall and remaining pipe thickness, depth of corrosion pits and deposit. Tangential radiography is the most convenient technique for measuring the remaining wall thickness of corroded pipes and for assessing the thickness and location of deposits. In this technique, a view of pipe cross-section, including a view of pipe wall, is projected on to a film, enabling direct measurement of the pipe wall thickness. Proper geometrical relations must be established between the source of radiation, the specimen and the film so that the radiograph can be properly interpreted.

Density measurement method is another technique for measurement of remaining wall and deposit thicknesses and pit depth. This method is an alternative of the first method and bases on measuring the radiographic densities of the sound and pitted areas, using density-thickness graphs. The radiation reaching the film changes with the thickness of the material. Any discontinuity, pit or wall thinning of the material allows more radiation to pass and therefore causes higher density areas on the film. The density-thickness curve can be established by exposing a stepped block having the same material as the pipe and covering the thickness range up to the twice pipe wall, and then correlating the thickness with densities of each step.

Both methods described above can be considered as complementary of each other and may show difficulties in the large diameter pipes or in the case of pits associated with deposit.

4. EXPERIMENTAL SET-UP

Tangential radiography was used for remaining wall thickness, pit depth and deposit determination in RRT samples. Schematic illustration of the experimental set-up for tangential radiography is given in figure 4.

Two X ray tubes (Seifert Eresco, 300 kV, 5 mA and Andrex Smart 225 kV, 4 mA) and vacupack radiographic films (Agfa D7 with 0.027 mm Pb front and back) were used for the RRT samples. Positions 1 and 2 in figure 4 were used for small diameter pipes. Position 1 was applied for the density measurement method. In this method, also a stepped reference block covering the double wall thickness of the pipe was placed on the same film beside the pipe, to draw a density-thickness curve.

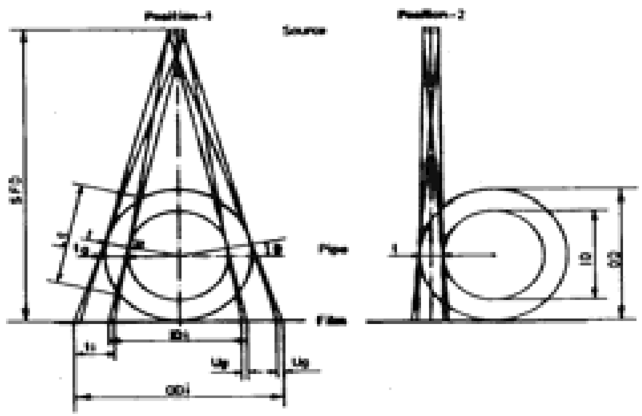

FIG. 4. Schematic illustration of the experimental set-up.

5. EXPERIMENTS

The round robin test (RRT) samples of Turkey and of other participating countries in the group were tested by tangential radiography. The density measurement method was applied on the original pipe of Turkish RRT samples, with specimen number TUR-ORG-P3. Before testing of each part an examination instruction was prepared by following the general rules of ISO 5579. As an example, the examination instruction of the RRT sample TUR-FAB-P1 is given. As it can be seen from the instruction, there are several exposure positions in order to fully locate the flaws and deposit.

Determination the depths of flaws was performed by applying the exposure positions P3, P4 and P5, which are the same as position 2 in figure 4. Position 2 in figure 4 was also applied for the determination of pit depths of the corroded pipe sample TUR-ORG-P3, which was used for the density measurement method. In the density measurement method, the pipe was exposed together with a reference block having 4 mm, 7 mm, 10 mm and 13 mm thick steps, according to position 1 in figure 4.

The exposure parameters were selected in order to obtain a density between 2 and 4 depending on the identification problems of the OD and ID extremities of the pipe. A density of about 2 was satisfactory to reveal the flaws, however for a clear definition of the ID extremity higher densities up to 4 was required. The source-to-film distance was selected as large as possible in order to decrease the penumbra and therefore to improve the definition. All the exposure parameters used are given.

6. RESULTS

Radiographic examination of each RRT sample was reported by using a special report form prepared by Turkish project team. As an example, the radiographic test report of the RRT sample TUR-FAB-P1 is given. The flaws and their locations and dimensions are shown in the report. The results obtained and the problems encountered during testing of the RRT samples were presented and discussed during the 2nd RCM held in Damascus. Turkey has completed his RRT programme after the 2nd RCM because of delay of Syrian RRT samples, which were shipped through France.

Figure 5 shows the radiograph of the specimen TUR-FAB-P1. All the artificial flaws and deposit can be identified on this radiograph. Fig.6 shows the radiograph of the same specimen, which was taken by turning the pipe to be tangential at the machined hole. From this radiograph, the depth of the machined hole can be measured very easily. The radiograph was taken at higher density (about 4) to obtain a better identification of pipe wall ID and deposit extremities.

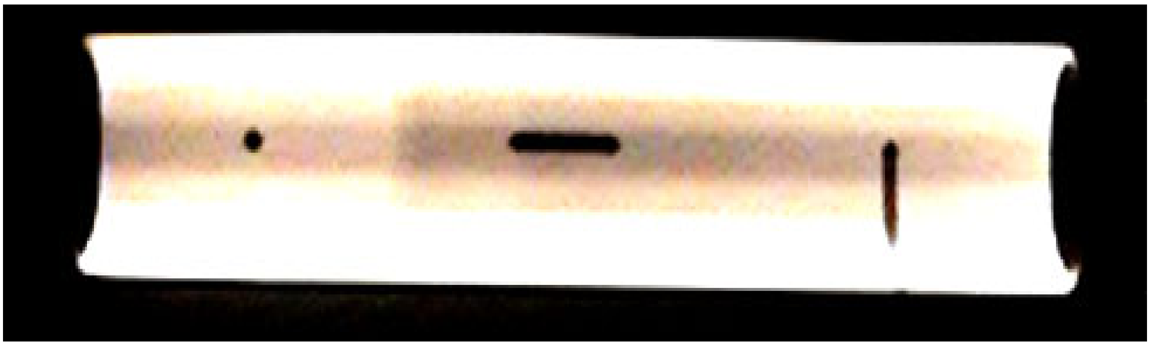

FIG. 5. Print of radiograph of sample TUR-FAB-P1 (exp.pos1, SFD: 700 mm, 180 kV, 5 mA, 4 min, Film: Agfa D7 Pb, Density: 2.7).

FIG. 6. Print of radiograph of sample TUR-FAB-P1 tangential at the machined hole (exp. pos2, SFD: 700 mm, 200 kV, 5 mA, 5 min, Film: Agfa D7 Pb, Density: 4).

The radiograph of the elbow sample TUR-FAB-E2 is shown in figure 7. Artificial wall thinning can be well identified on this radiograph.

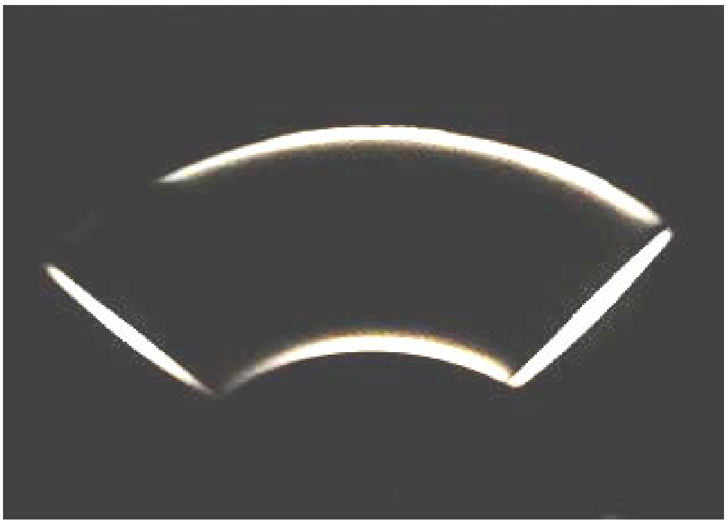

FIG. 7. Print of radiograph of sample TUR-FAB-E2 (exp. pos1, SFD: 700 mm, 200 kV, 5 mA, 5 min, Film: Agfa D7 Pb, Density: 4).

The radiograph of the corroded pipe sample TUR-ORG-P3 is given in figure 8. The radiograph of the same pipe taken tangential at the pits and for high density is shown in figure 9. Remaining wall thickness and three pits on the OD surface of the pipe were determined by both tangential technique and density measurement method. The results of both methods are comparable.

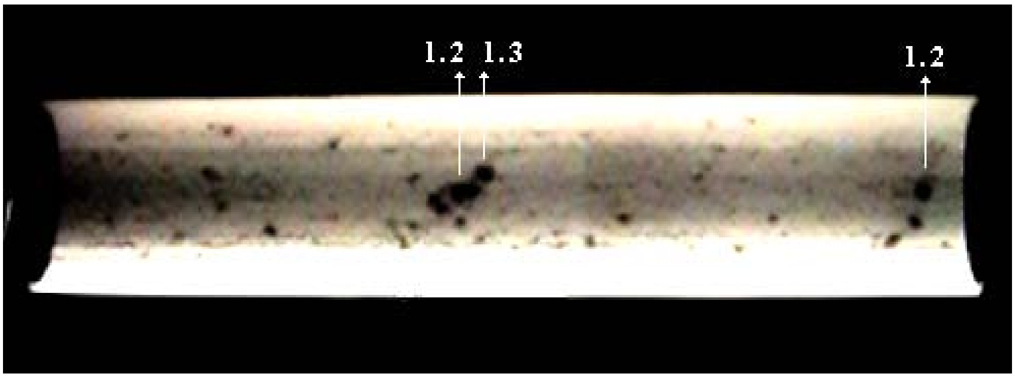

FIG. 8. Print of radiograph of corroded pipe sample TUR-ORG-P3 (exp. pos1, SFD: 700 mm, 160 kV, 5 mA, 4 min, Film: Agfa D7 Pb, Density: 2).

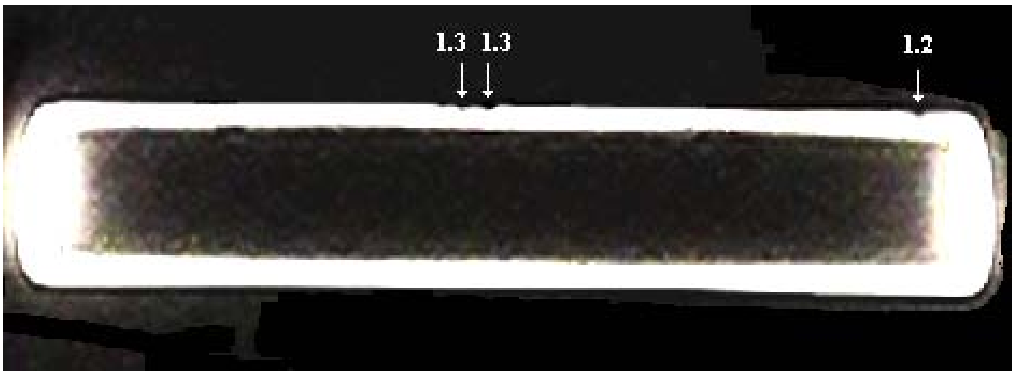

FIG. 9. Print of radiograph of same pipe as in figure 8 tangential at the pits (exp. pos.2, SFD: 700 mm, 180 kV, 5 mA, 6 min, Film: Agfa D7 Pb, Density: 4).

The density thickness curve used for the remaining wall thickness and pit depths evaluations is given in figure 10.

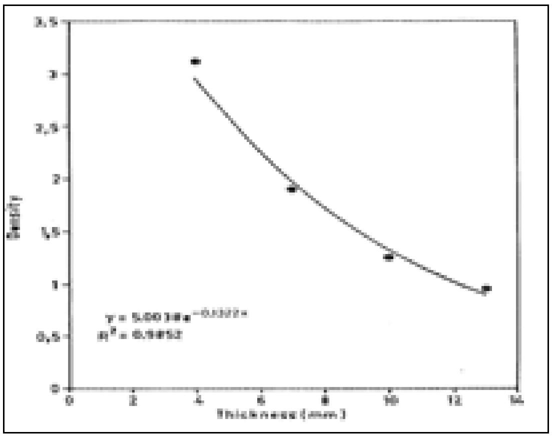

FIG. 10. Density-thickness curve established with a reference block of 4 mm, 7 mm, 10 mm and 13 mm thick steps (SFD: 700 mm, 160 kV, 5 mA, 4 min, Film:Agfa D7 Pb).

When evaluating by using this reference curve, the reading of densities on the pipe radiograph were made on areas corresponding to the uppermost locations of the pipe which is equivalent to minimum material thickness. Away from these locations, the method gives false results because of the circular geometry of the pipe cross-section. Also the pits were evaluated under same conditions as pipe wall.

After completing the radiographic examinations and evaluations of the RRT samples of the Mediterranean group, mechanical and ultrasonic measurements were made on the Turkish RRT samples. The corroded pipe sample TUR-ORG-P3 was cut into 4 pieces to use for destructive measurements. Figure 11 shows this pipe as destructed. The other two samples were measured mechanically and ultrasonically without any destruction (Figure 12).

FIG. 11. Mechanical measurements on the corroded pipe sample TUR-FAB-P3 which is destructed.

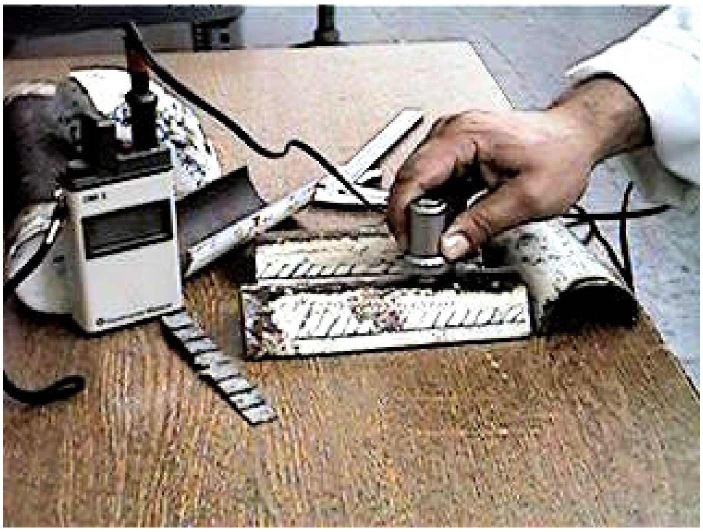

FIG. 12. Ultrasonic measurements on the corroded pipe sample TUR-FAB-P3 which is destructed.

The results of mechanical and ultrasonic measurements of Turkish RRT samples are given in table I.

TABLE I. RESULTS OF RADIOGRAPHIC EXAMINATIONS OF RRT SAMPLES TESTED BY TURKEY

Specimen No.	Specimen details	Nature of defects	Tested by	Test Parameters	Results
TUR-FAB-P1	OD = 60 mm NT = 4 mm L =300 mm	Long and circular. notches, drilled hole and partially deposit	TUR	Source: X ray Int.:5 mA Focus: 3 mm Volt: 180 kV SDF: 700 mm Exp. Time: 4 min. Dev.: 5 min. at 20^0C	Wall thickness: 4 mm Notch depths: Long notch: 2.5 mm Circ. notch: 2 mm Hole: 2 mm Deposit.: 2 min., 6 max.
TUR-FAB-E2	OD 0 60 mm NT = 4 mm Elbow 90^0C	Artificial wall degradation (2 pieces)	TUR	Source: x ray Int.:5 mA Focus: 3 mm Volt: 200 kV SDF: 700 mm Exp. Time: 5 min. Dev.: 5 min. at 20^0C	Remaining wall at cylinder hole: 0.5-1 mm Wall degrad.: 2 mm
TUR-ORG-P3	OD = 60 mm NT = 3.5 mm L = 300 mm	Natural pits	TUR	Source: X ray Int.:5 mA Focus: 3 mm Volt: 160, 180 kV SDF: 700 mm Exp. Time: 4, 6 min. Dev.: 5 min. at 20^0C	Wall thickness: 3.15 mm (form density meas. tech) Pits depths: 1.2 mm, 1.3 mm, 1.2 mm
FRA1	OD =60 mm NT = 4 mm L = 300 mm	Corrosion	TUR	Source: x ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 120 kV SDF: 700 mm Exp. Time: 2,3,4 min. Dev.: manual t =5 min.; T = 20^0C	Pit.dia.: 6 mm
FRA 2	OD=115 mm NT = 6 mm L = 300mm	3 corrosion pits and circular. Notches (artificial)	TUR	Source: x ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 140, 150 kV SDF: 700 mm Exp. Time: 2min,3 min. Dev.: manual t =5 min.; T = 20^0C	Wall thick: 6 mm 3 pits: ϕ6, ϕ10, ϕ10
FRA 3	OD= 167mm NT= 6 mm L = 310 mm	2 corrosion pits and 3 half circ. notches, half-ring	TUR	Source: x ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 150, 160, 180 kV SDF: 700 mm Exp. Time: 3min, 4 min. Dev.: manual t = 5 min.; T = 20^0C	Pit dia: 10 mm Wall thickness: 6 mm

Specimen No.	Specimen details	Nature of defects	Tested by	Test Parameters	Results
ALG1	OD =100mm NT = 4 mm L: Bend	1 corrosion pit and 1 circumferential notch+1 half. circ. notch	TUR	Source: X ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 120, 140 kV SDF: 700 mm Exp. Time: 2.5 min. Dev.: manual, 5 min. at 20^0C	Pit depth: 5 mm Wall th.: 4 mm
ALG2	OD=230 mm NT = 6 mm L = 230 mm	Longitude & circular notches	TUR	Source: X ray Int.:4 mA Focus: 1.6x1.6 mm Volt: 120, 140 kV SDF: 700,1500,2000mm Exp. Time: 2.5 min. Dev.: 5 min. at 20^0C	Wall thickness: 6 mm Length of notches: 60, 60 and 75 mm Width: 2 mm

SYR O1	OD=114 mm NT = 4 mm L – bend 3 mm min. elbow	Randomly distributed small pits	TUR	Source: X ray Volt: 160, 180 kV Int.:5 mA Focus: 3 mm SDF: 700 mm Exp. Time: 4 min., 4 min., 4 min. Dev.: 5 min. at 20^0C manually	Remaining wall thickness: 3 mm min. 4 mm. max.
SYR F1	OD=110 mm NT = 5 mm Leng.:300 mm Straight pipe	3 artificial ID grooves, each circumflex	TUR	Source: X ray Volt: 180 kV Int.:5 mA Focus: 3 mm SDF: 700 mm Exp. Time: 2 min., 3 min., 3 min. Dev.: 5 min. at 20^0C manually	Remaining wall thickness: 2 mm min. 4.5 mm. max. Width of grooves: 63 mm, 33 mm and 33 mm respectively.
SYR F2	OD=108 mm NT =4 mm Length: 300 mm Straight pipe	3 artificial ID grooves,2 artificial OD grooves, each circumflex	TUR	Source: X ray Volt: 180 kV Int.:5 mA Focus: 3 mm SDF: 700 mm Exp. Time: 2 min., 2 min., 2 min., 2 min Dev.: 5 min. at 20^0C manually	Remaining wall thickness: 2 mm min. 3.5 mm. max. Width of OD grooves: 25 mm and 20 mm respectively. Width of ID grooves: 52 mm, 26 mm and 25 mm respectively
Unknown Sample	OD = 64 mm NT =3.5 mm L = 300 mm Straight pipe	General corrosion, pits, artificial deposit	TUR	Source: X ray Volt: 160, 170 kV Int.:5 mA Focus: 3 mm SDF: 700 mm Exp. Time: 5 min., 7min Dev.: 5 min. at 20^0C manually	Remaining wall thickness: 3.5 mm. overall General corrosion with randomly distributed pits. Artificial deposit including cracks centric hole

The results of Turkish RRT samples measured by mechanical tools and ultrasonic are given in table II.

TABLE II. THE RESULTS OF TURKISH RRT SAMPLES MEASURED BY MECHANICAL TOOLS AND ULTRASONIC

Specimen No	Specimen details	Nature of defects	Tested by	Mechanical measurement	Ultrasonic measurement
TUR-FAB-P1	OD = 60mm NT = 4mm Length.: 300mm	Artificial defects: - long. notch - circ. notch - drilled hole - concentric deposit	TUR	Wall thick.: 4,4 mm Artificial defects: - long. notch:2,2mm deep - circ. notch: 2mm deep - drilled hole: 2,5mm deep - concentric deposit: 2,2mm min.- 6,6mm max.	Wall thick, 4,4 mm
TUR-FAB-E2	OD = 60mm NT = 4mm 90^0 elbow	Artificial defects: 2 types of wall degradation	TUR	Wall thick.: 4 mm Remaining wall thick. at wall degrad 1: 0,7mm min. Remaining wall thick. at wall degrad 2: 1,2 mm	Wall thick. 4 mm remaining wall th. at wall degrad 1: 0,7mm min. remaining wall th. at wall degrad 2: 1,2 mm
TUR-ORG-P3	OD = 60mm NT = 3,5mm Length.: 300mm	Natural corrosion pits	TUR	Remaining wall th.:3,2-3,6 mm Depth of pit 1:1,2mm Depth of pit 2:1,1mm Depth of pit 3:1,3mm	Remaining wall thick: 3,2-3,6 mm

7. CONCLUSIONS AND RECOMMENDATIONS

The tangential radiography is an accurate method for the determination of remaining pipe wall, deposit thickness and pit depth. Exposure parameters, such as radiation type and energy, source-to-film distance, position of the source relative to the pipe, exposure time thus the film density and the type of radiographic film are very important with respect to obtain a good image definition.

Exposure position 2 in figure 4 seems to be more advantageous than position 1, since the OD and ID tangent points are almost symmetrical and θ is practically zero, thus no correction in image dimension is necessary, except geometrical enlargement and penumbra. The SFD should be as large as possible. An SFD of about 8 times of the pipe's OD is sufficient to make the enlargement and the penumbra negligible.

The film density between 2 and 4 is appropriate for a good definition depending on pipe diameter, wall thickness and type of radiation used. Selection of radiation energy and optimum film density are important because of burn-off at the pipe's OD and subject contrast at the ID tangent point. The outer portion of the pipe wall is thin for the radiation energies, which are selected for the double thickness of the pipe wall, and this causes burn-off at the OD extremity of the pipe and thus reading error. This problem can be solved by using low-density radiographs (2 or less) or by placing a reference block close to the OD tangent point of the pipe.

The poor definition at the ID extremity of the pipe wall is another problem. The change of the material thickness from the ID tangent point to the center of the pipe is very gradual. The result is low subject contrast and poor accuracy in the reading of wall image at the ID extremity. The problem is more evidently in larger diameter pipes, if especially the wall thickness of a pipe is larger but the diameter is the same. This can be improved by using large SFD and high film density (about 4). It has to be noted here too that larger SFD requires longer exposure time. The longer the exposure time the more is the adverse effect of the scattered radiation on the radiographic contrast. Therefore an optimum SFD, exposure time and thus film density shall be determined experimentally to obtain a good image definition.

X rays are mainly suitable for the tangential radiography of small diameter pipes, while Ir-192 may also be used if the wall thickness of the pipe is within the thickness range of the source. In order to decrease the burn-off at the OD extremity of the pipe a filtration can be made in front of the tube window.

Double film methods may also be applied to obtain a good definition at the OD and ID extremities, by using two films of same speed in one cassette or two films of different speeds.

The density measurement method is applied as a double wall technique and can be used for remaining wall thickness and pit depth measurement. This method gives the average wall thickness of the pipe and no estimation can be made about minimum and maximum thicknesses. If the pipe includes deposit, special simulations are required for correct estimation of wall thickness and pit depth. Also the average deposit thickness can be determined by the aid of these simulations.

In the case of larger diameter pipes (e.g. > 150 mm OD), density measurement method may give false results in the determination of the pit depth if the exposure was taken while the pit lay on the source side of pipe's upper wall. Since the distance from the upper wall to the film is large, that causes spreading of the radiation beam, which is passing through the pit cross-section, and lower density of the pit image compared to the lower wall. This requires the exposure of the pipe from opposite side relative to the first exposure if possible. This problem may be neglected in small diameter pipes (< 150 mm OD).

Both tangential and density measurement methods are very powerful for remaining wall thickness, pit depth and deposit measurements and can be considered as complementary of each other. The results obtained by two methods on RRT samples were comparable. The measurements carried out with ultrasonic and mechanical tools were also comparable with radiographic measurements.

In the operational pipelines, the contrast of the pipe wall ID extremities will be lower, because the density difference between the pipe material and liquid inside the pipe is smaller compared to the empty pipe. Determination of deposit is also difficult in the operational pipelines because of very small density difference between the deposit and liquid.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY. First RCM report on validation of protocols for corrosion and deposit determination in pipes by radiography, Çekmece Nuclear Research and Training Centre, Istanbul, 15-19 Sept.1997.

[2] PETERS B.F., “Radiography for corrosion evaluation”, Mater.Eval. March 1965, pp.129–135.

[3] BURKLE W.S, “Application of tangential radiography technique for evaluating pipe system erosion/corrosion”, Mater.Eval. Vol. 47, Oct. 1989.

[4] IAEA. Second RCM report on validation of protocols for corrosion and deposit determination in pipes by radiography, Syrian Atomic Energy Commission, Damascus, 17-20 May 1999.

[5] EKINCI S. ET AL., “Corrosion and deposit measurements in pipes by radiographic techniques”, Insight, Vol.40,No. 9, Sept. 1998.

BIBLIOGRAPHY

BILLEAUDEAUX, J.K., Tangential radiography using a radiation gauge, Mat. Eval. (1992).

BURKE, W.S., Application of the tangential radiographic technique for evaluation pipe system erosion/corrosion, Mat. Eval. (1989).

CABE, D., Radiography of main steam piping welds enclosed with guard pipe, Mat. Eval. (1989).

CHERUBINI, G., LANDONI, A., et al., Integrated system for digitization, interactive processing, presentation and storage of film-supported industrial radiography images, 6th EC NDT, Nice (1994).

DAMASCENO, S., DE OLIVEIRA, C.H.F., Determination of parameters for gamma ray examination in operation pipelines, XIII WCNDT, São Paulo (1992).

DRUVY, J.C., Corrosion monitoring and thickness measurement — What are we doing wrong?, Insight Vol.39, No.1, Jan. 1997, P. 17–20.

EDELMANN, X., AMMIRATO, F.V., Reliability of NDT in the nuclear industry, 6th EC NDT, Nice (1994).

EDGLEY, J.S., Detection of corrosion fatigue cracking in boiler water wall tubes using constant potential X rays, NDT Australia 26(4) (1989).

EIZEMBER, A.C., Optical archiving of digitised radiographs, Automatic Radiologic NDT II, ASNT (1990).

FLEUET, E., LAVAYSSIÈRE, B., Un système d'aide à l'interprétation de radiographie industrielle, 6ème CE, CND, Nice (1994).

FONTANA, M., Corrosion engineering (3rd ed.) McGraw Hill Inc., N.Y., 1986, P. 220–256.

GONDARD, CH., et al., Analysis of radiographic films through modelisation of the data acquisition line and a "simulated annealing" algorithm, 14 WCNDT, New Delhi (1996).

GRIFFITH, L.K., TWYMAN, D.R., Digitome model DT36: a film based computer tomographic system, Automatic Radiologic II, ASNT (1990).

GRIFFITHS, R., Overview of oil refinery corrosion monitoring, NDT Australia 26 (1) (1989).

HARCHENKO, V.V., et al., Radiographic testing of complex-shape multilayer structures and X ray anomalous transfer effect, XIII WCNDT, São Paulo (1992).

HASKINS, J.J., FRITT, W.T., Material characterisation using digitised radiographs, Autom. Radiol. NDT II (1990).

HEIDT, H., NOCKERMANN, CHR., THOMSEN, N., ROC: how to describe the reliability of NDT quantitatively, Automatic Radiologic NDT II, ASNT (1990).

HERBERT, H. UHLIG, WINETON REVIE, R., Corrosion and corrosion control (3rd ed.) John Wiley & Sons Inc., N.Y. (1985) 165–186.

IYONS, T.D., Pipeline inspection using a dry X ray film, 3M Co., St. Paul, MN, USA (1990).

KINSELLA, T.E., JEAGER, M.J., SOLTANI, P.K., Issues related with the implementation of phosphor imaging in industrial radiography, Material Evaluation, Vol. No. 56, April 98, p. 540.

KOSHOV, T.C., et al., Radiographic image enhancement using opaque fillers in adhesive systems, 14 WCNDT, New Delhi (1996).

KOTOUZAS, M.K., ROGERSON, J.H., The quality management of NDT operations, Insight (1995).

KROLICKI, R.P., Internal corrosion examination and wall thickness measurement of pipe by radiographic method, Mat. Eval (1977).

LAHIRI, et al., NDE of delaminating and voids in axis-symmetric CRFP shells: Part A — Scope and limitation of tangential X ray radiography, XIII MCNDT, São Paulo (1992).

LAUTZENHEISER, C.E., NDT methods for corrosion detection, Material protection, August 1963 p. 72.

LAVAYSSIÈRE, B., FLEUET, E., GEORGEL B., Reconstruction en 3 dimensions un nouveau défi en radiographie industrielle, 6ème CE CND, Nice (1994).

LISTWAN, W., DOBROWOLSKI, M., Fragment dealing with radiographic testing of deposits in pipes, Gamma Radiography Manual, WNT, Warsaw (in Polish) (1964).

LOTT, P.W., LOTT, J., Near real-time radiologic corrosion monitoring of arctic petroleum gathering lines, Mat. Eval. (1985).

MARKS, P.T., RAY, M., Study of erosion/corrosion detection methods as applied in the refinery – petrochemical industries, Houston, Texas.

MARKS, P.T., The generation of error in interpretation, International Chemical and Petroleum Industry Inspection Technology III, ASNT (1993).

NOVAT, J., DESCHAMPS, J., Point de vue de l'autorité de sûreté sur la démonstration de performance de CND dans le nucléaire, 6ème CE CND, Nice (1994).

ONG, P.S., et al., Transcatter X ray technique for the inspection of insulated, oil-carrying pipelines, Review of Progress in Quantitative NDE **12** (1993).

Outil d'assistance numérique à l'analyse de radiogrammes, SIRAC/HORUS, France (1995).

PEARCE, J.T.H., A layman's Guide, Insight Vol.39, No.1, Jan. 1997, P. 10–16.

PETERS, B.F., Radiography for corrosion evaluation, Mat. Eval., March 1965

PORTER, R., Ultrasonic thickness surveys on tankers and bulk carriers, Insight Vol. 39, No.1, p. 21–23.

ROGERS, J., Validity of calibration and test data: Application of ISO/IEC Guide 25 (EN 45001) or the ISO 9000 series, Insight (1995).

RUDIN, J.R., Review of existing and possible techniques for corrosion under insulation and wall thickness measurement in steel pressure containments, Insight Vol. 39, No. 6, June 1997, p. 413–417.

WESSEL, H., NOCKERMANN, C., TILLAK, G., Digitization of industrial radiographic films, 6^{th} EC NDT, Nice (1994).

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